

US009750443B2

(12) **United States Patent**
Smith et al.

(10) **Patent No.:** **US 9,750,443 B2**
(45) **Date of Patent:** **Sep. 5, 2017**

(54) **MULTIPLE WAVELENGTH SENSOR EMITTERS**

(71) Applicant: **Cercacor Laboratories, Inc.**, Irvine, CA (US)

(72) Inventors: **Robert Smith**, Lake Forest, CA (US); **David Dalke**, Rancho Santa Margarita, CA (US); **Ammar Al-Ali**, San Juan Capistrano, CA (US); **Mohamed Diab**, Ladera Ranch, CA (US); **Marcelo Lamego**, Cupertino, CA (US)

(73) Assignee: **CERCACOR LABORATORIES, INC.**, Irvine, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 420 days.

(21) Appl. No.: **14/472,760**

(22) Filed: **Aug. 29, 2014**

(65) **Prior Publication Data**
US 2015/0133755 A1 May 14, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/776,065, filed on Feb. 25, 2013, now Pat. No. 8,849,365, which is a (Continued)

(51) **Int. Cl.**
A61B 5/1455 (2006.01)
G06F 19/00 (2011.01)
(Continued)

(52) **U.S. Cl.**
CPC **A61B 5/1455** (2013.01); **A61B 5/0022** (2013.01); **A61B 5/0205** (2013.01); (Continued)

(58) **Field of Classification Search**
CPC A61B 5/1455; A61B 5/742; A61B 5/6826; A61B 5/14532; A61B 5/0205; (Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,910,701 A 10/1975 Henderson et al.
3,998,550 A 12/1976 Konishi et al.
(Continued)

FOREIGN PATENT DOCUMENTS

DE 3244695 C2 10/1985
EP 41 92 23 3/1991
(Continued)

OTHER PUBLICATIONS

US 8,845,543, 09/2014, Diab et al. (withdrawn)
(Continued)

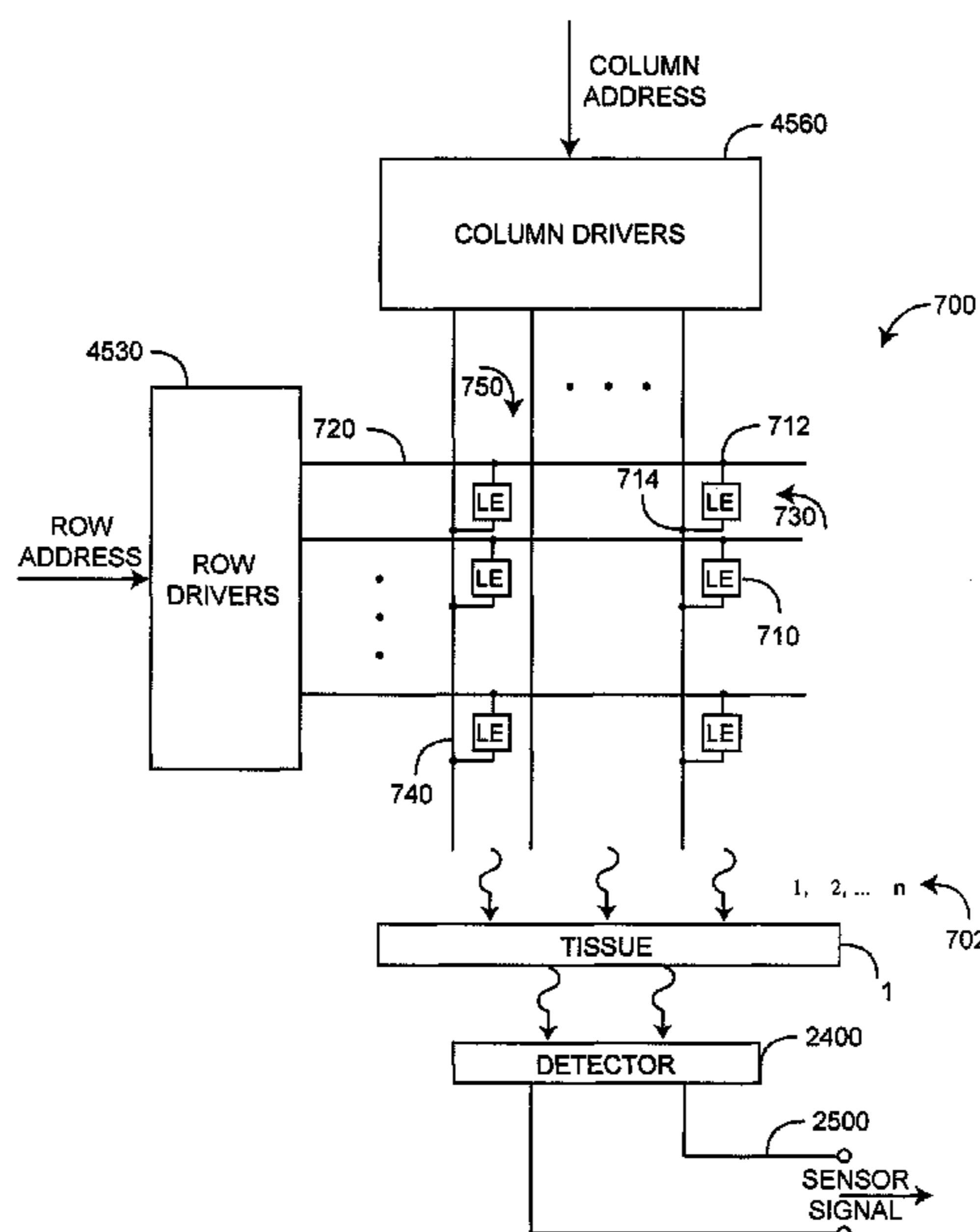
Primary Examiner — Eric Winakur

(74) *Attorney, Agent, or Firm* — Knobbe, Martens, Olson & Bear, LLP

(57) **ABSTRACT**

A physiological sensor has light emitting sources, each activated by addressing at least one row and at least one column of an electrical grid. The light emitting sources are capable of transmitting light of multiple wavelengths and a detector is responsive to the transmitted light after attenuation by body tissue.

19 Claims, 48 Drawing Sheets



Related U.S. Application Data

continuation of application No. 12/422,915, filed on Apr. 13, 2009, now Pat. No. 8,385,996, which is a continuation of application No. 11/367,013, filed on Mar. 1, 2006, now Pat. No. 7,764,982.

(60) Provisional application No. 60/657,281, filed on Mar. 1, 2005, provisional application No. 60/657,268, filed on Mar. 1, 2005, provisional application No. 60/657,759, filed on Mar. 1, 2005, provisional application No. 60/657,596, filed on Mar. 1, 2005.

(51) **Int. Cl.**

- A61B 5/0205* (2006.01)
- A61B 5/145* (2006.01)
- A61B 5/00* (2006.01)
- A61B 5/026* (2006.01)
- A61B 5/0295* (2006.01)
- A61B 5/1495* (2006.01)
- A61B 1/00* (2006.01)
- A61B 5/024* (2006.01)

(52) **U.S. Cl.**

- CPC *A61B 5/0261* (2013.01); *A61B 5/0295* (2013.01); *A61B 5/02416* (2013.01); *A61B 5/1495* (2013.01); *A61B 5/14532* (2013.01); *A61B 5/14546* (2013.01); *A61B 5/14551* (2013.01); *A61B 5/14552* (2013.01); *A61B 5/6815* (2013.01); *A61B 5/6826* (2013.01); *A61B 5/6829* (2013.01); *A61B 5/6832* (2013.01); *A61B 5/6838* (2013.01); *A61B 5/7221* (2013.01); *A61B 5/7246* (2013.01); *A61B 5/7275* (2013.01); *A61B 5/7278* (2013.01); *A61B 5/742* (2013.01); *A61B 5/7405* (2013.01); *A61B 5/746* (2013.01); *A61B 5/7475* (2013.01); *G06F 19/3418* (2013.01); *A61B 1/00* (2013.01); *A61B 5/02427* (2013.01); *A61B 2562/08* (2013.01); *A61B 2562/085* (2013.01); *A61B 2562/222* (2013.01); *Y10S 439/909* (2013.01)

(58) **Field of Classification Search**

- CPC *A61B 5/14551*; *A61B 5/14552*; *A61B 5/14546*; *A61B 2562/085*
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,014,321 A 3/1977 March
 4,051,522 A 9/1977 Healy et al.
 4,157,708 A 6/1979 Imura
 4,167,331 A 9/1979 Nielsen
 4,266,554 A 5/1981 Hamaguri
 4,267,844 A 5/1981 Yamanishi
 4,295,475 A 10/1981 Torzala
 4,331,161 A 5/1982 Patel
 4,399,824 A 8/1983 Davidson
 4,446,871 A 5/1984 Imura
 4,531,527 A 7/1985 Reinhold, Jr. et al.
 4,561,440 A 12/1985 Kubo et al.
 4,586,513 A 5/1986 Hamaguri
 4,603,700 A 8/1986 Nichols et al.
 4,621,643 A 11/1986 New et al.
 4,653,498 A 3/1987 New, Jr. et al.
 4,655,225 A 4/1987 Dahne et al.
 4,685,464 A 8/1987 Goldberger et al.
 4,694,833 A 9/1987 Hamaguri
 4,695,955 A 9/1987 Faisandier
 4,700,708 A 10/1987 New et al.
 4,714,341 A 12/1987 Hamaguri et al.

4,770,179 A 9/1988 New et al.
 4,773,422 A 9/1988 Isaacson et al.
 4,781,195 A 11/1988 Martin
 4,800,885 A 1/1989 Johnson
 4,805,623 A 2/1989 Jobsis
 4,822,997 A 4/1989 Fuller et al.
 4,832,484 A 5/1989 Aoyagi et al.
 4,846,183 A 7/1989 Martin
 4,854,328 A 8/1989 Pollack
 4,863,265 A 9/1989 Flower et al.
 4,867,571 A 9/1989 Frick et al.
 4,868,476 A 9/1989 Respaut
 4,869,254 A 9/1989 Stone et al.
 4,890,306 A 12/1989 Noda
 4,907,876 A 3/1990 Suzuki et al.
 4,911,167 A 3/1990 Corenman et al.
 4,934,372 A 6/1990 Corenman et al.
 4,938,218 A 7/1990 Goodman et al.
 4,942,877 A 7/1990 Sakai et al.
 4,955,379 A 9/1990 Hall
 4,960,126 A 10/1990 Conlon et al.
 4,960,128 A 10/1990 Gordon et al.
 4,964,010 A 10/1990 Miyasaka et al.
 4,964,408 A 10/1990 Hink et al.
 4,967,571 A 11/1990 Sporri
 4,975,581 A 12/1990 Robinson et al.
 4,975,647 A 12/1990 Downer et al.
 4,986,665 A 1/1991 Yamanishi et al.
 4,996,975 A 3/1991 Nakamura
 4,997,769 A 3/1991 Lundsgaard
 5,003,979 A 4/1991 Merickel et al.
 5,025,791 A 6/1991 Niwa
 RE33,643 E 7/1991 Isaacson et al.
 5,028,787 A 7/1991 Rosenthal et al.
 5,033,472 A 7/1991 Sato et al.
 5,041,187 A 8/1991 Hink et al.
 5,054,495 A 10/1991 Uemura et al.
 5,058,588 A 10/1991 Kaestle et al.
 5,069,213 A 12/1991 Polczynski
 5,077,476 A 12/1991 Rosenthal
 5,078,136 A 1/1992 Stone et al.
 5,101,825 A 4/1992 Gravenstein et al.
 5,137,023 A 8/1992 Mendelson et al.
 5,155,697 A 10/1992 Bunsen
 5,162,725 A 11/1992 Hodson et al.
 5,163,438 A 11/1992 Gordon et al.
 5,188,108 A 2/1993 Secker
 5,189,609 A 2/1993 Tivig et al.
 5,190,040 A 3/1993 Aoyagi
 5,209,230 A 5/1993 Swedlow et al.
 5,226,053 A 7/1993 Cho et al.
 5,226,417 A 7/1993 Swedlow et al.
 5,246,002 A 9/1993 Prosser
 5,247,931 A 9/1993 Norwood
 5,259,381 A 11/1993 Chung
 5,267,562 A 12/1993 Ukawa et al.
 5,267,563 A 12/1993 Swedlow et al.
 5,278,627 A 1/1994 Aoyagi
 5,297,548 A 3/1994 Pologe
 5,313,940 A 5/1994 Fuse et al.
 5,319,355 A 6/1994 Russek
 5,331,549 A 7/1994 Crawford, Jr.
 5,335,659 A 8/1994 Pologe et al.
 5,337,744 A 8/1994 Branigan
 5,337,745 A 8/1994 Benaron
 5,341,805 A 8/1994 Stavridi et al.
 5,348,004 A 9/1994 Hollub
 5,351,685 A 10/1994 Potratz
 5,355,129 A 10/1994 Baumann
 5,355,880 A 10/1994 Thomas et al.
 5,355,882 A 10/1994 Ukawa et al.
 5,361,758 A 11/1994 Hall et al.
 5,368,041 A 11/1994 Shambroom
 5,368,224 A 11/1994 Richardson et al.
 D353,195 S 12/1994 Savage et al.
 D353,196 S 12/1994 Savage et al.
 5,370,114 A 12/1994 Wong et al.
 5,372,136 A 12/1994 Steuer et al.
 5,377,676 A 1/1995 Vari et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

5,383,874 A	1/1995	Jackson et al.	5,719,589 A	2/1998	Norman et al.
5,385,143 A	1/1995	Aoyagi	5,720,284 A	2/1998	Aoyagi et al.
5,387,122 A	2/1995	Goldberger et al.	5,720,293 A	2/1998	Quinn et al.
5,392,777 A	2/1995	Swedlow et al.	D393,830 S	4/1998	Tobler et al.
5,400,267 A	3/1995	Denen et al.	5,742,718 A	4/1998	Harman et al.
5,413,101 A	5/1995	Sugiura	5,743,262 A	4/1998	Lepper, Jr. et al.
D359,546 S	6/1995	Savage et al.	5,743,263 A	4/1998	Baker, Jr.
5,421,329 A	6/1995	Casciani et al.	5,746,206 A	5/1998	Mannheimer
5,424,545 A	6/1995	Block et al.	5,746,697 A	5/1998	Swedlow et al.
5,425,362 A	6/1995	Siker et al.	5,752,914 A	5/1998	Delonzor et al.
5,425,375 A	6/1995	Chin et al.	5,755,226 A	5/1998	Carim et al.
5,427,093 A	6/1995	Ogawa et al.	5,758,644 A	6/1998	Diab et al.
5,429,128 A	7/1995	Cadell et al.	5,760,910 A	6/1998	Lepper, Jr. et al.
5,431,170 A	7/1995	Mathews	5,769,785 A	6/1998	Diab et al.
5,435,309 A	7/1995	Thomas et al.	5,772,587 A	6/1998	Gratton et al.
D361,840 S	8/1995	Savage et al.	5,779,630 A	7/1998	Fein et al.
D362,063 S	9/1995	Savage et al.	5,782,237 A	7/1998	Casciani et al.
5,452,717 A	9/1995	Branigan et al.	5,782,756 A	7/1998	Mannheimer
D363,120 S	10/1995	Savage et al.	5,782,757 A	7/1998	Diab et al.
5,456,252 A	10/1995	Vari et al.	5,785,659 A	7/1998	Caro et al.
5,469,845 A	11/1995	DeLonzor et al.	5,790,729 A	8/1998	Pologe et al.
RE35,122 E	12/1995	Corenman et al.	5,791,347 A	8/1998	Flaherty et al.
5,479,934 A	1/1996	Imran	5,792,052 A	8/1998	Isaacson et al.
5,482,036 A	1/1996	Diab et al.	5,793,485 A	8/1998	Gourley
5,487,386 A	1/1996	Wakabayashi et al.	5,800,348 A	9/1998	Kaestle et al.
5,490,505 A	2/1996	Diab et al.	5,800,349 A	9/1998	Isaacson et al.
5,490,523 A	2/1996	Isaacson et al.	5,803,910 A	9/1998	Potratz
5,494,032 A	2/1996	Robinson et al.	5,807,246 A	9/1998	Sakaguchi et al.
5,494,043 A	2/1996	O'Sullivan et al.	5,807,247 A	9/1998	Merchant et al.
5,503,148 A	4/1996	Pologe et al.	5,810,723 A	9/1998	Aldrich
5,520,177 A	5/1996	Ogawa et al.	5,810,724 A	9/1998	Gronvall
5,528,519 A	6/1996	Ohkura et al.	5,810,734 A	9/1998	Caro et al.
5,533,507 A	7/1996	Potratz	5,817,010 A	10/1998	Hibl
5,533,511 A	7/1996	Kaspari et al.	5,818,985 A	10/1998	Merchant et al.
5,534,851 A	7/1996	Russek	5,823,950 A	10/1998	Diab et al.
5,551,423 A	9/1996	Sugiura	5,823,952 A	10/1998	Levinson et al.
5,553,615 A	9/1996	Carim et al.	5,827,182 A	10/1998	Raley et al.
5,555,882 A	9/1996	Richardson et al.	5,830,121 A	11/1998	Enomoto et al.
5,561,275 A	10/1996	Savage et al.	5,830,131 A	11/1998	Caro et al.
5,562,002 A	10/1996	Lalin	5,830,137 A	11/1998	Scharf
5,575,284 A	11/1996	Athan et al.	5,833,618 A	11/1998	Caro et al.
5,577,500 A	11/1996	Potratz	5,839,439 A	11/1998	Nierlich et al.
5,584,299 A	12/1996	Sakai et al.	RE36,000 E	12/1998	Swedlow et al.
5,588,427 A	12/1996	Tien	5,842,979 A	12/1998	Jarman
5,590,649 A	1/1997	Caro et al.	5,846,190 A	12/1998	Woehrle
5,590,652 A	1/1997	Inai	5,850,443 A	12/1998	Van Oorschot et al.
5,595,176 A	1/1997	Yamaura	5,851,178 A	12/1998	Aronow
5,596,992 A	1/1997	Haaland et al.	5,851,179 A	12/1998	Ritson et al.
5,602,924 A	2/1997	Durand et al.	5,853,364 A	12/1998	Baker, Jr. et al.
5,603,323 A	2/1997	Pflugrath et al.	5,857,462 A	1/1999	Thomas et al.
5,603,623 A	2/1997	Nishikawa et al.	5,860,099 A	1/1999	Milios et al.
5,615,672 A	4/1997	Braig et al.	5,860,919 A	1/1999	Kiani-Azarbayjany et al.
5,617,857 A	4/1997	Chader et al.	5,865,736 A	2/1999	Baker, Jr. et al.
5,630,413 A	5/1997	Thomas et al.	5,876,348 A	3/1999	Sugo
5,632,272 A	5/1997	Diab et al.	5,885,213 A	3/1999	Richardson et al.
5,638,816 A	6/1997	Kiani-Azarbayjany et al.	5,890,929 A	4/1999	Mills et al.
5,638,818 A	6/1997	Diab et al.	5,891,022 A	4/1999	Pologe
5,645,059 A	7/1997	Fein et al.	5,891,024 A	4/1999	Jarman et al.
5,645,060 A	7/1997	Yorkey	5,900,632 A	5/1999	Sterling et al.
5,645,440 A	7/1997	Tobler et al.	5,904,654 A	5/1999	Wohlmann et al.
5,651,780 A	7/1997	Jackson et al.	5,910,108 A	6/1999	Solenberger
5,658,248 A	8/1997	Klein et al.	5,916,154 A	6/1999	Hobbs et al.
5,660,567 A	8/1997	Nierlich et al.	5,919,133 A	7/1999	Taylor
5,662,106 A	9/1997	Swedlow et al.	5,919,134 A	7/1999	Diab
5,676,139 A	10/1997	Goldberger et al.	5,921,921 A	7/1999	Potratz et al.
5,676,141 A	10/1997	Hollub	5,934,277 A	8/1999	Mortz
5,678,544 A	10/1997	DeLonzor et al.	5,934,925 A	8/1999	Tobler et al.
5,685,299 A	11/1997	Diab et al.	5,939,609 A	8/1999	Knapp et al.
5,685,301 A	11/1997	Klomhaus	5,940,182 A	8/1999	Lepper, Jr. et al.
5,687,719 A	11/1997	Sato et al.	5,954,644 A	9/1999	Dettling
5,687,722 A	11/1997	Tien et al.	5,976,466 A	11/1999	Ratner et al.
5,690,104 A	11/1997	Kanemoto et al.	5,978,691 A	11/1999	Mills
5,692,503 A	12/1997	Kuenstner	5,983,122 A	11/1999	Jarman et al.
5,697,371 A	12/1997	Aoyagi	5,987,343 A	11/1999	Kinast
5,713,355 A	2/1998	Richardson et al.	5,991,355 A	11/1999	Dahlke
			5,995,855 A	11/1999	Kiani et al.
			5,995,856 A	11/1999	Mannheimer et al.
			5,995,859 A	11/1999	Takahashi
			5,997,343 A	12/1999	Mills et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

5,999,841	A	12/1999	Aoyagi et al.	6,336,900	B1	1/2002	Alleckson et al.
6,002,952	A	12/1999	Diab et al.	6,339,715	B1	1/2002	Bahr et al.
6,006,119	A	12/1999	Soller et al.	6,341,257	B1	1/2002	Haaland
6,011,986	A	1/2000	Diab et al.	6,343,224	B1	1/2002	Parker
6,014,576	A	1/2000	Raley	6,349,228	B1	2/2002	Kiani et al.
6,018,673	A	1/2000	Chin et al.	6,351,658	B1	2/2002	Middleman et al.
6,018,674	A	1/2000	Aronow	6,356,774	B1	3/2002	Bernstein et al.
6,023,541	A	2/2000	Merchant et al.	6,360,113	B1	3/2002	Dettling
6,027,452	A	2/2000	Flaherty et al.	6,360,114	B1	3/2002	Diab et al.
6,035,223	A	3/2000	Baker, Jr.	6,363,269	B1	3/2002	Hanna et al.
6,036,642	A	3/2000	Diab et al.	6,368,283	B1	4/2002	Xu et al.
6,045,509	A	4/2000	Caro et al.	6,371,921	B1	4/2002	Caro et al.
6,064,898	A	5/2000	Aldrich	6,374,129	B1	4/2002	Chin et al.
6,067,462	A	5/2000	Diab et al.	6,377,828	B1	4/2002	Chaiken et al.
6,068,594	A	5/2000	Schloemer et al.	6,377,829	B1	4/2002	Al-Ali
6,073,037	A	6/2000	Alam et al.	6,388,240	B2	5/2002	Schulz et al.
6,081,735	A	6/2000	Diab et al.	6,393,310	B1	5/2002	Kuentner
6,083,172	A	7/2000	Baker, Jr. et al.	6,397,091	B2	5/2002	Diab et al.
6,088,607	A	7/2000	Diab et al.	6,397,092	B1	5/2002	Norris et al.
6,094,592	A	7/2000	Yorkey et al.	6,397,093	B1	5/2002	Aldrich
6,104,938	A	8/2000	Huiku	6,408,198	B1	6/2002	Hanna et al.
6,110,522	A	8/2000	Lepper, Jr. et al.	6,411,833	B1	6/2002	Baker, Jr. et al.
6,112,107	A	8/2000	Hannula	6,415,166	B1	7/2002	Van Hoy et al.
6,122,042	A	9/2000	Wunderman et al.	6,415,233	B1	7/2002	Haaland
6,124,597	A	9/2000	Shehada et al.	6,415,236	B2	7/2002	Kobayashi et al.
6,128,521	A	10/2000	Marro et al.	6,421,549	B1	7/2002	Jacques
6,129,675	A	10/2000	Jay	6,430,437	B1	8/2002	Marro
6,132,363	A	10/2000	Freed et al.	6,430,525	B1	8/2002	Weber et al.
6,144,868	A	11/2000	Parker	6,434,408	B1	8/2002	Heckel
6,149,588	A	11/2000	Noda et al.	6,441,388	B1	8/2002	Thomas et al.
6,151,516	A	11/2000	Kiani-Azarbayjany et al.	6,453,184	B1	9/2002	Hyogo et al.
6,151,518	A	11/2000	Hayashi	6,455,340	B1	9/2002	Chua et al.
6,152,754	A	11/2000	Gerhardt et al.	6,463,310	B1	10/2002	Swedlow et al.
6,154,667	A	11/2000	Miura et al.	6,463,311	B1	10/2002	Diab
6,157,041	A	12/2000	Thomas et al.	6,466,824	B1	10/2002	Struble
6,157,850	A	12/2000	Diab et al.	6,470,199	B1	10/2002	Kopotic et al.
6,163,715	A	12/2000	Larsen et al.	6,480,729	B2	11/2002	Stone
6,165,005	A	12/2000	Mills et al.	6,490,466	B1	12/2002	Fein et al.
6,165,173	A	12/2000	Kamdar et al.	6,490,684	B1	12/2002	Fenstermaker et al.
6,174,283	B1	1/2001	Nevo et al.	6,497,659	B1	12/2002	Rafert
6,175,752	B1	1/2001	Say et al.	6,501,974	B2	12/2002	Huiku
6,184,521	B1	2/2001	Coffin et al.	6,501,975	B2	12/2002	Diab et al.
6,192,261	B1	2/2001	Gratton et al.	6,504,943	B1	1/2003	Sweatt et al.
6,206,830	B1	3/2001	Diab et al.	6,505,059	B1	1/2003	Kollias et al.
6,226,539	B1	5/2001	Potratz	6,505,060	B1	1/2003	Norris
6,229,856	B1	5/2001	Diab et al.	6,505,061	B2	1/2003	Larson
6,230,035	B1	5/2001	Aoyagi et al.	6,505,133	B1	1/2003	Hanna
6,232,609	B1	5/2001	Snyder et al.	6,510,329	B2	1/2003	Heckel
6,236,872	B1	5/2001	Diab et al.	6,515,273	B2	2/2003	Al-Ali
6,237,604	B1	5/2001	Burnside et al.	6,519,486	B1	2/2003	Edgar, Jr. et al.
6,241,683	B1	6/2001	Macklem et al.	6,519,487	B1	2/2003	Parker
6,248,083	B1	6/2001	Smith et al.	6,522,398	B2	2/2003	Cadell et al.
6,253,097	B1	6/2001	Aronow et al.	6,525,386	B1	2/2003	Mills et al.
6,256,523	B1	7/2001	Diab et al.	6,526,300	B1	2/2003	Kiani et al.
6,262,698	B1	7/2001	Blum	6,526,301	B2	2/2003	Larsen et al.
6,263,222	B1	7/2001	Diab et al.	6,528,809	B1	3/2003	Thomas et al.
6,266,551	B1	7/2001	Osadchy et al.	6,537,225	B1	3/2003	Mills
6,272,363	B1	8/2001	Casciani et al.	6,541,756	B2	4/2003	Schulz et al.
6,278,522	B1	8/2001	Lepper, Jr. et al.	6,542,763	B1	4/2003	Yamashita et al.
6,280,213	B1	8/2001	Tobler et al.	6,542,764	B1	4/2003	Al-Ali et al.
6,285,895	B1	9/2001	Ristolainen et al.	6,545,652	B1	4/2003	Tsuji
6,285,896	B1	9/2001	Tobler et al.	6,546,267	B1	4/2003	Sugiura
6,295,330	B1	9/2001	Skog et al.	6,553,241	B2	4/2003	Mannheimer et al.
6,298,252	B1	10/2001	Kovach et al.	6,564,077	B2	5/2003	Mortara
6,298,255	B1	10/2001	Cordero et al.	6,571,113	B1	5/2003	Fein et al.
6,301,493	B1	10/2001	Marro et al.	6,580,086	B1	6/2003	Schulz et al.
6,304,675	B1	10/2001	Osbourn et al.	6,582,964	B1	6/2003	Samsoundar et al.
6,304,767	B1	10/2001	Soller et al.	6,584,336	B1	6/2003	Ali et al.
6,308,089	B1 *	10/2001	von der Ruhr	6,584,413	B1	6/2003	Keenan et al.
		 A61B 5/00	6,591,123	B2	7/2003	Fein et al.
			600/338	6,594,511	B2	7/2003	Stone et al.
6,317,627	B1	11/2001	Ennen et al.	6,594,518	B1	7/2003	Benaron et al.
6,321,100	B1	11/2001	Parker	6,595,316	B2	7/2003	Cybulski et al.
6,325,761	B1	12/2001	Jay	6,597,932	B2	7/2003	Tian et al.
6,330,468	B1	12/2001	Scharf	6,597,933	B2	7/2003	Kiani et al.
6,334,065	B1	12/2001	Al-Ali et al.	6,600,940	B1	7/2003	Fein et al.
				6,606,509	B2	8/2003	Schmitt
				6,606,510	B2	8/2003	Swedlow et al.
				6,606,511	B1	8/2003	Ali et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

6,609,016 B1	8/2003	Lynn	6,788,849 B1	9/2004	Pawluczyk
6,611,698 B1	8/2003	Yamashita et al.	6,792,300 B1	9/2004	Diab et al.
6,614,521 B2	9/2003	Samsoondar et al.	6,800,373 B2	10/2004	Gorczyca
6,615,064 B1	9/2003	Aldrich	6,801,797 B2	10/2004	Mannheimer et al.
6,615,151 B1	9/2003	Scecina et al.	6,801,799 B2	10/2004	Mendelson
6,618,602 B2	9/2003	Levin	6,810,277 B2	10/2004	Edgar, Jr. et al.
6,622,095 B2	9/2003	Kobayashi et al.	6,813,511 B2	11/2004	Diab et al.
6,628,975 B1	9/2003	Fein et al.	6,816,741 B2	11/2004	Diab
6,631,281 B1	10/2003	Kastle	6,819,950 B2	11/2004	Mills
6,632,181 B2	10/2003	Flaherty et al.	6,822,564 B2	11/2004	Al-Ali
6,639,668 B1	10/2003	Trepagnier	6,825,619 B2	11/2004	Norris
6,640,116 B2	10/2003	Diab	6,826,419 B2	11/2004	Diab et al.
6,643,530 B2	11/2003	Diab et al.	6,829,496 B2	12/2004	Nagai et al.
6,645,142 B2	11/2003	Braig et al.	6,829,501 B2	12/2004	Nielsen et al.
6,650,917 B2	11/2003	Diab et al.	6,830,711 B2	12/2004	Mills et al.
6,654,623 B1	11/2003	Kastle	6,836,679 B2	12/2004	Baker, Jr. et al.
6,654,624 B2	11/2003	Diab et al.	6,839,579 B1	1/2005	Chin
6,657,717 B2	12/2003	Cadell et al.	6,839,580 B2	1/2005	Zonios et al.
6,658,276 B2	12/2003	Kianl et al.	6,839,582 B2	1/2005	Heckel
6,658,277 B2	12/2003	Wasserman	6,842,702 B2	1/2005	Haaland et al.
6,661,161 B1	12/2003	Lanzo et al.	6,845,256 B2	1/2005	Chin et al.
6,662,033 B2	12/2003	Casciani et al.	6,847,835 B1	1/2005	Yamanishi
6,665,551 B1	12/2003	Suzuki	6,850,787 B2	2/2005	Weber et al.
6,668,183 B2	12/2003	Hicks et al.	6,850,788 B2	2/2005	Al-Ali
6,671,526 B1	12/2003	Aoyagi et al.	6,852,083 B2	2/2005	Caro et al.
6,671,531 B2	12/2003	Al-Ali et al.	6,861,639 B2	3/2005	Al-Ali
6,675,031 B1	1/2004	Porges et al.	6,861,641 B1	3/2005	Adams
6,675,106 B1	1/2004	Keenan et al.	6,869,402 B2	3/2005	Arnold
6,676,600 B1	1/2004	Conero et al.	6,882,874 B2	4/2005	Huiku
6,678,543 B2	1/2004	Diab et al.	6,898,452 B2	5/2005	Al-Ali et al.
6,681,126 B2	1/2004	Solenberger	6,912,049 B2	6/2005	Pawluczyk et al.
6,684,090 B2	1/2004	Ali et al.	6,917,422 B2	7/2005	Samsoondar et al.
6,684,091 B2	1/2004	Parker	6,919,566 B1	7/2005	Cadell
6,687,620 B1	2/2004	Haaland et al.	6,920,345 B2	7/2005	Al-Ali et al.
6,690,466 B2	2/2004	Miller et al.	6,921,367 B2	7/2005	Mills
6,694,157 B1	2/2004	Stone et al.	6,922,645 B2	7/2005	Haaland et al.
6,697,655 B2	2/2004	Sueppel et al.	6,928,311 B1	8/2005	Pawluczyk et al.
6,697,656 B1	2/2004	Al-Ali	6,931,268 B1	8/2005	Kiani-Azarbayjany et al.
6,697,657 B1	2/2004	Shehada et al.	6,931,269 B2	8/2005	Terry
6,697,658 B2	2/2004	Al-Ali	6,934,570 B2	8/2005	Kiani et al.
RE38,476 E	3/2004	Diab et al.	6,939,305 B2	9/2005	Flaherty et al.
6,699,194 B1	3/2004	Diab et al.	6,943,348 B1	9/2005	Coffin IV
6,701,170 B2	3/2004	Stetson	6,944,487 B2	9/2005	Maynard et al.
6,708,049 B1	3/2004	Berson et al.	6,950,687 B2	9/2005	Al-Ali
6,711,503 B2	3/2004	Haaland	6,956,572 B2	10/2005	Zaleski
6,714,803 B1	3/2004	Mortz	6,961,598 B2	11/2005	Diab
6,714,804 B2	3/2004	Al-Ali et al.	6,970,792 B1	11/2005	Diab
6,714,805 B2	3/2004	Jeon et al.	6,975,891 B2	12/2005	Pawluczyk
RE38,492 E	4/2004	Diab et al.	6,979,812 B2	12/2005	Al-Ali
6,719,705 B2	4/2004	Mills	6,985,764 B2	1/2006	Mason et al.
6,720,734 B2	4/2004	Norris	6,987,994 B1	1/2006	Mortz
6,721,582 B2	4/2004	Trepagnier et al.	6,993,371 B2	1/2006	Kiani et al.
6,721,584 B2	4/2004	Baker, Jr. et al.	6,996,427 B2	2/2006	Ali et al.
6,721,585 B1	4/2004	Parker	6,999,904 B2	2/2006	Weber et al.
6,725,074 B1	4/2004	Kastle	7,001,337 B2	2/2006	Dekker
6,725,075 B2	4/2004	Al-Ali	7,003,338 B2	2/2006	Weber et al.
6,726,634 B2	4/2004	Freeman	7,003,339 B2	2/2006	Diab et al.
6,728,560 B2	4/2004	Kollias et al.	7,006,856 B2	2/2006	Baker, Jr. et al.
6,735,459 B2	5/2004	Parker	7,015,451 B2	3/2006	Dalke et al.
6,741,875 B1	5/2004	Pawluczyk et al.	7,024,233 B2	4/2006	Ali et al.
6,741,876 B1	5/2004	Scecina et al.	7,027,849 B2	4/2006	Al-Ali
6,743,172 B1	6/2004	Blike	7,030,749 B2	4/2006	Al-Ali
6,745,060 B2	6/2004	Diab et al.	7,039,449 B2	5/2006	Al-Ali
6,745,061 B1	6/2004	Hicks et al.	7,041,060 B2	5/2006	Flaherty et al.
6,748,253 B2	6/2004	Norris et al.	7,044,918 B2	5/2006	Diab
6,748,254 B2	6/2004	O'Neil et al.	7,067,893 B2	6/2006	Mills et al.
6,754,515 B1	6/2004	Pologe	7,096,052 B2	8/2006	Mason et al.
6,754,516 B2	6/2004	Mannheimer	7,096,054 B2	8/2006	Abdul-Hafiz et al.
6,760,607 B2	7/2004	Al-Ali	7,132,641 B2	11/2006	Schulz et al.
6,760,609 B2	7/2004	Jacques	7,142,901 B2	11/2006	Kiani et al.
6,770,028 B1	8/2004	Ali et al.	7,149,561 B2	12/2006	Diab
6,771,994 B2	8/2004	Kiani et al.	7,186,966 B2	3/2007	Al-Ali
6,773,397 B2	8/2004	Kelly	7,190,261 B2	3/2007	Al-Ali
6,778,923 B2	8/2004	Norris et al.	7,215,984 B2	5/2007	Diab et al.
6,780,158 B2	8/2004	Yarita	7,215,986 B2	5/2007	Diab et al.
			7,221,971 B2	5/2007	Diab et al.
			7,225,006 B2	5/2007	Al-Ali et al.
			7,225,007 B2	5/2007	Al-Ali et al.
			RE39,672 E	6/2007	Shehada et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

7,239,905 B2	7/2007	Kiani-Azarbayjany et al.	7,844,313 B2	11/2010	Kiani et al.
7,245,953 B1	7/2007	Parker	7,844,314 B2	11/2010	Al-Ali
7,254,429 B2	8/2007	Schurman et al.	7,844,315 B2	11/2010	Al-Ali
7,254,431 B2	8/2007	Al-Ali et al.	7,865,222 B2	1/2011	Weber et al.
7,254,433 B2	8/2007	Diab et al.	7,873,497 B2	1/2011	Weber et al.
7,254,434 B2	8/2007	Schulz et al.	7,880,606 B2	2/2011	Al-Ali
7,272,425 B2	9/2007	Al-Ali	7,880,626 B2	2/2011	Al-Ali et al.
7,274,955 B2	9/2007	Kiani et al.	7,891,355 B2	2/2011	Al-Ali et al.
D554,263 S	10/2007	Al-Ali	7,894,868 B2	2/2011	Al-Ali et al.
7,280,858 B2	10/2007	Al-Ali et al.	7,899,507 B2	3/2011	Al-Ali et al.
7,289,835 B2	10/2007	Mansfield et al.	7,899,518 B2	3/2011	Trepagnier et al.
7,292,883 B2	11/2007	De Felice et al.	7,904,132 B2	3/2011	Weber et al.
7,295,866 B2	11/2007	Al-Ali	7,909,772 B2	3/2011	Popov et al.
7,299,080 B2	11/2007	Acosta et al.	7,910,875 B2	3/2011	Al-Ali
7,328,053 B1	2/2008	Diab et al.	7,919,713 B2	4/2011	Al-Ali et al.
7,332,784 B2	2/2008	Mills et al.	7,937,128 B2	5/2011	Al-Ali
7,340,287 B2	3/2008	Mason et al.	7,937,129 B2	5/2011	Mason et al.
7,341,559 B2	3/2008	Schulz et al.	7,937,130 B2	5/2011	Diab et al.
7,343,186 B2	3/2008	Lamego et al.	7,941,199 B2	5/2011	Kiani
D566,282 S	4/2008	Al-Ali et al.	7,951,086 B2	5/2011	Flaherty et al.
7,355,512 B1	4/2008	Al-Ali	7,957,780 B2	6/2011	Lamego et al.
7,356,365 B2	4/2008	Schurman	7,962,188 B2	6/2011	Kiani et al.
7,371,981 B2	5/2008	Abdul-Hafiz	7,962,190 B1	6/2011	Diab et al.
7,373,193 B2	5/2008	Al-Ali et al.	7,976,472 B2	7/2011	Kiani
7,373,194 B2	5/2008	Weber et al.	7,988,637 B2	8/2011	Diab
7,376,453 B1	5/2008	Diab et al.	7,990,382 B2	8/2011	Kiani
7,377,794 B2	5/2008	Al-Ali et al.	7,991,446 B2	8/2011	Ali et al.
7,377,899 B2	5/2008	Weber et al.	8,000,761 B2	8/2011	Al-Ali
7,383,070 B2	6/2008	Diab et al.	8,008,088 B2	8/2011	Bellott et al.
7,415,297 B2	8/2008	Al-Ali et al.	RE42,753 E	9/2011	Kiani-Azarbayjany et al.
7,428,432 B2	9/2008	Ali et al.	8,019,400 B2	9/2011	Diab et al.
7,438,683 B2	10/2008	Al-Ali et al.	8,028,701 B2	10/2011	Al-Ali et al.
7,440,787 B2	10/2008	Diab	8,029,765 B2	10/2011	Bellott et al.
7,454,240 B2	11/2008	Diab et al.	8,036,727 B2	10/2011	Schurman et al.
7,467,002 B2	12/2008	Weber et al.	8,036,728 B2	10/2011	Diab et al.
7,469,157 B2	12/2008	Diab et al.	8,046,040 B2	10/2011	Ali et al.
7,471,969 B2	12/2008	Diab et al.	8,046,041 B2	10/2011	Diab et al.
7,471,971 B2	12/2008	Diab et al.	8,046,042 B2	10/2011	Diab et al.
7,483,729 B2	1/2009	Al-Ali et al.	8,048,040 B2	11/2011	Kiani
7,483,730 B2	1/2009	Diab et al.	8,050,728 B2	11/2011	Al-Ali et al.
7,489,958 B2	2/2009	Diab et al.	RE43,169 E	2/2012	Parker
7,496,391 B2	2/2009	Diab et al.	8,118,620 B2	2/2012	Al-Ali et al.
7,496,393 B2	2/2009	Diab et al.	8,126,528 B2	2/2012	Diab et al.
D587,657 S	3/2009	Al-Ali et al.	8,128,572 B2	3/2012	Diab et al.
7,499,741 B2	3/2009	Diab et al.	8,130,105 B2	3/2012	Al-Ali et al.
7,499,835 B2	3/2009	Weber et al.	8,145,287 B2	3/2012	Diab et al.
7,500,950 B2	3/2009	Al-Ali et al.	8,150,487 B2	4/2012	Diab et al.
7,509,154 B2	3/2009	Diab et al.	8,175,672 B2	5/2012	Parker
7,509,494 B2	3/2009	Al-Ali	8,180,420 B2	5/2012	Diab et al.
7,510,849 B2	3/2009	Schurman et al.	8,182,443 B1	5/2012	Kiani
7,526,328 B2	4/2009	Diab et al.	8,185,180 B2	5/2012	Diab et al.
7,530,942 B1	5/2009	Diab	8,190,223 B2	5/2012	Al-Ali et al.
7,530,949 B2	5/2009	Al Ali et al.	8,190,227 B2	5/2012	Diab et al.
7,530,955 B2	5/2009	Diab et al.	8,203,438 B2	6/2012	Kiani et al.
7,563,110 B2	7/2009	Al-Ali et al.	8,203,704 B2	6/2012	Merritt et al.
7,596,398 B2	9/2009	Al-Ali et al.	8,204,566 B2	6/2012	Schurman et al.
7,606,861 B2	10/2009	Killcommons et al.	8,219,172 B2	7/2012	Schurman et al.
7,618,375 B2	11/2009	Flaherty et al.	8,224,411 B2	7/2012	Al-Ali et al.
D606,659 S	12/2009	Kiani et al.	8,228,181 B2	7/2012	Al-Ali
7,647,083 B2	1/2010	Al-Ali et al.	8,229,532 B2	7/2012	Davis
D609,193 S	2/2010	Al-Ali et al.	8,229,533 B2	7/2012	Diab et al.
7,670,726 B2	3/2010	Lu	8,233,955 B2	7/2012	Al-Ali et al.
7,679,519 B2	3/2010	Lindner et al.	8,244,325 B2	8/2012	Al-Ali et al.
D614,305 S	4/2010	Al-Ali et al.	8,255,026 B1	8/2012	Al-Ali
RE41,317 E	5/2010	Parker	8,255,027 B2	8/2012	Al-Ali et al.
7,729,733 B2	6/2010	Al-Ali et al.	8,255,028 B2	8/2012	Al-Ali et al.
7,734,320 B2	6/2010	Al-Ali	8,260,577 B2	9/2012	Weber et al.
7,761,127 B2	7/2010	Al-Ali et al.	8,265,723 B1	9/2012	McHale et al.
7,761,128 B2	7/2010	Al-Ali et al.	8,274,360 B2	9/2012	Sampath et al.
7,764,982 B2	7/2010	Dalke et al.	8,301,217 B2	10/2012	Al-Ali et al.
D621,516 S	8/2010	Kiani et al.	8,306,596 B2	11/2012	Schurman et al.
7,791,155 B2	9/2010	Diab	8,310,336 B2	11/2012	Muhsin et al.
7,801,581 B2	9/2010	Diab	8,315,683 B2	11/2012	Al-Ali et al.
7,822,452 B2	10/2010	Schurman et al.	RE43,860 E	12/2012	Parker
RE41,912 E	11/2010	Parker	8,337,403 B2	12/2012	Al-Ali et al.
			8,346,330 B2	1/2013	Lamego
			8,353,842 B2	1/2013	Al-Ali et al.
			8,355,766 B2	1/2013	MacNeish, III et al.
			8,359,080 B2	1/2013	Diab et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

8,364,223 B2	1/2013	Al-Ali et al.	8,721,542 B2	5/2014	Al-Ali et al.
8,364,226 B2	1/2013	Diab et al.	8,723,677 B1	5/2014	Kiani
8,374,665 B2	2/2013	Lamego	8,740,792 B1	6/2014	Kiani et al.
8,385,995 B2	2/2013	Al-Ali et al.	8,754,776 B2	6/2014	Poeze et al.
8,385,996 B2	2/2013	Dalke et al.	8,755,535 B2	6/2014	Telfort et al.
8,388,353 B2	3/2013	Kiani et al.	8,755,856 B2	6/2014	Diab et al.
8,399,822 B2	3/2013	Al-Ali	8,755,872 B1	6/2014	Marinow
8,401,602 B2	3/2013	Kiani	8,761,850 B2	6/2014	Lamego
8,405,608 B2	3/2013	Al-Ali et al.	8,764,671 B2	7/2014	Kiani
8,414,499 B2	4/2013	Al-Ali et al.	8,768,423 B2	7/2014	Shakespeare et al.
8,418,524 B2	4/2013	Al-Ali	8,771,204 B2	7/2014	Telfort et al.
8,423,106 B2	4/2013	Lamego et al.	8,777,634 B2	7/2014	Kiani et al.
8,428,967 B2	4/2013	Olsen et al.	8,781,543 B2	7/2014	Diab et al.
8,430,817 B1	4/2013	Al-Ali et al.	8,781,544 B2	7/2014	Al-Ali et al.
8,437,825 B2	5/2013	Dalvi et al.	8,781,549 B2	7/2014	Al-Ali et al.
8,455,290 B2	6/2013	Siskavich	8,788,003 B2	7/2014	Schurman et al.
8,457,703 B2	6/2013	Al-Ali	8,790,268 B2	7/2014	Al-Ali
8,457,707 B2	6/2013	Kiani	8,801,613 B2	8/2014	Al-Ali et al.
8,463,349 B2	6/2013	Diab et al.	8,821,397 B2	9/2014	Al-Ali et al.
8,466,286 B2	6/2013	Bellott et al.	8,821,415 B2	9/2014	Al-Ali et al.
8,471,713 B2	6/2013	Poeze et al.	8,830,449 B1	9/2014	Lamego et al.
8,473,020 B2	6/2013	Kiani et al.	8,831,700 B2	9/2014	Schurman et al.
8,483,787 B2	7/2013	Al-Ali et al.	8,840,549 B2	9/2014	Al-Ali et al.
8,489,364 B2	7/2013	Weber et al.	8,847,740 B2	9/2014	Kiani et al.
8,498,684 B2	7/2013	Weber et al.	8,849,365 B2	9/2014	Smith et al.
8,504,128 B2	8/2013	Blank et al.	8,852,094 B2	10/2014	Al-Ali et al.
8,509,867 B2	8/2013	Workman et al.	8,852,994 B2	10/2014	Wojtczuk et al.
8,515,509 B2	8/2013	Bruinsma et al.	8,868,147 B2	10/2014	Stippick et al.
8,523,781 B2	9/2013	Al-Ali	8,868,150 B2	10/2014	Al-Ali et al.
8,529,301 B2	9/2013	Al-Ali et al.	8,870,792 B2	10/2014	Al-Ali et al.
8,532,727 B2	9/2013	Al-Ali et al.	8,886,271 B2	11/2014	Kiani et al.
8,532,728 B2	9/2013	Diab et al.	8,888,539 B2	11/2014	Al-Ali et al.
D692,145 S	10/2013	Al-Ali et al.	8,888,708 B2	11/2014	Diab et al.
8,547,209 B2	10/2013	Kiani et al.	8,892,180 B2	11/2014	Weber et al.
8,548,548 B2	10/2013	Al-Ali	8,897,847 B2	11/2014	Al-Ali
8,548,549 B2	10/2013	Schurman et al.	8,909,310 B2	12/2014	Lamego et al.
8,548,550 B2	10/2013	Al-Ali et al.	8,912,909 B2	12/2014	Al-Ali et al.
8,560,032 B2	10/2013	Al-Ali et al.	8,921,699 B2	12/2014	Al-Ali et al.
8,560,034 B1	10/2013	Diab et al.	8,929,964 B2	1/2015	Al-Ali et al.
8,570,167 B2	10/2013	Al-Ali	8,942,777 B2	1/2015	Diab et al.
8,570,503 B2	10/2013	Vo et al.	8,948,834 B2	2/2015	Diab et al.
8,571,617 B2	10/2013	Reichgott et al.	8,965,471 B2	2/2015	Lamego et al.
8,571,618 B1	10/2013	Lamego et al.	8,996,085 B2	3/2015	Kiani et al.
8,571,619 B2	10/2013	Al-Ali et al.	8,998,809 B2	4/2015	Kiani
8,577,431 B2	11/2013	Lamego et al.	9,028,429 B2	5/2015	Telfort et al.
8,581,732 B2	11/2013	Al-Ali et al.	9,066,680 B1	6/2015	Al-Ali et al.
8,584,345 B2	11/2013	Al-Ali et al.	9,072,474 B2	7/2015	Al-Ali et al.
8,588,880 B2	11/2013	Abdul-Hafiz et al.	9,107,626 B2	8/2015	Al-Ali et al.
8,600,467 B2	12/2013	Al-Ali et al.	9,119,595 B2	9/2015	Lamego
8,606,342 B2	12/2013	Diab	9,131,882 B2	9/2015	Al-Ali et al.
8,626,255 B2	1/2014	Al-Ali et al.	9,131,917 B2	9/2015	Telfort et al.
8,630,691 B2	1/2014	Lamego et al.	9,138,180 B1	9/2015	Coverston et al.
8,634,889 B2	1/2014	Al-Ali et al.	9,153,112 B1	10/2015	Kiani et al.
8,641,631 B2	2/2014	Sierra et al.	9,153,121 B2	10/2015	Kiani et al.
8,652,060 B2	2/2014	Al-Ali	9,192,329 B2	11/2015	Al-Ali
8,663,107 B2	3/2014	Kiani	9,192,351 B1	11/2015	Telfort et al.
8,666,468 B1	3/2014	Al-Ali	9,195,385 B2	11/2015	Al-Ali et al.
8,667,967 B2	3/2014	Al-Ali et al.	9,211,095 B1	12/2015	Al-Ali
8,670,811 B2	3/2014	O'Reilly	9,245,668 B1	1/2016	Vo et al.
8,670,814 B2	3/2014	Diab et al.	9,267,572 B2	2/2016	Barker et al.
8,676,286 B2	3/2014	Weber et al.	9,277,880 B2	3/2016	Poeze et al.
8,682,407 B2	3/2014	Al-Ali	9,295,421 B2	3/2016	Kiani et al.
RE44,823 E	4/2014	Parker	9,307,928 B1	4/2016	Al-Ali et al.
RE44,875 E	4/2014	Kiani et al.	D755,392 S	5/2016	Hwang et al.
8,690,799 B2	4/2014	Telfort et al.	9,326,712 B1	5/2016	Kiani
8,700,112 B2	4/2014	Kiani	9,364,181 B2	6/2016	Kiani et al.
8,702,627 B2	4/2014	Telfort et al.	9,368,671 B2	6/2016	Wojtczuk et al.
8,706,179 B2	4/2014	Parker	9,370,325 B2	6/2016	Al-Ali et al.
8,712,494 B1	4/2014	MacNeish, III et al.	9,370,335 B2	6/2016	Al-Ali et al.
8,715,206 B2	5/2014	Telfort et al.	9,375,185 B2	6/2016	Al-Ali et al.
8,718,735 B2	5/2014	Lamego et al.	9,386,953 B2	7/2016	Al-Ali
8,718,737 B2	5/2014	Diab et al.	9,386,961 B2	7/2016	Al-Ali et al.
8,718,738 B2	5/2014	Blank et al.	9,397,448 B2	7/2016	Al-Ali et al.
8,720,249 B2	5/2014	Al-Ali	9,436,645 B2	9/2016	Al-Ali et al.
8,721,541 B2	5/2014	Al-Ali et al.	9,492,110 B2	11/2016	Al-Ali et al.
			9,517,024 B2	12/2016	Kiani et al.
			9,538,949 B2	1/2017	Al-Ali et al.
			9,549,696 B2	1/2017	Lamego et al.
			2001/0044700 A1	11/2001	Kobayashi et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2001/0045532	A1	11/2001	Schulz et al.	2005/0143943	A1	6/2005	Brown
2002/0021269	A1	2/2002	Rast	2005/0148834	A1	7/2005	Hull et al.
2002/0026107	A1	2/2002	Kiani et al.	2005/0184895	A1	8/2005	Petersen et al.
2002/0035315	A1	3/2002	Ali et al.	2005/0187447	A1	8/2005	Chew et al.
2002/0035318	A1	3/2002	Mannheimer et al.	2005/0187448	A1	8/2005	Petersen et al.
2002/0038078	A1	3/2002	Ito	2005/0187449	A1	8/2005	Chew et al.
2002/0038081	A1	3/2002	Fein et al.	2005/0187450	A1	8/2005	Chew et al.
2002/0051290	A1	5/2002	Hannington	2005/0187452	A1	8/2005	Petersen et al.
2002/0059047	A1	5/2002	Haaland	2005/0187453	A1	8/2005	Petersen et al.
2002/0068858	A1	6/2002	Braig et al.	2005/0197549	A1	9/2005	Baker, Jr.
2002/0082488	A1	6/2002	Al-Ali et al.	2005/0197579	A1	9/2005	Baker, Jr.
2002/0095077	A1	7/2002	Swedlow et al.	2005/0197793	A1	9/2005	Baker, Jr.
2002/0095078	A1	7/2002	Mannheimer et al.	2005/0203357	A1	9/2005	Debreczeny et al.
2002/0111748	A1	8/2002	Kobayashi et al.	2005/0209515	A1	9/2005	Hockersmith et al.
2002/0115919	A1	8/2002	Al-Ali	2005/0228253	A1	10/2005	Debreczeny
2002/0154665	A1	10/2002	Funabashi et al.	2005/0250997	A1	11/2005	Takedo et al.
2002/0156353	A1	10/2002	Larson	2006/0030764	A1	2/2006	Porges et al.
2002/0159002	A1	10/2002	Chang	2006/0210120	A1	9/2006	Rowe et al.
2002/0161291	A1	10/2002	Kianl et al.	2006/0211922	A1	9/2006	Al-Ali et al.
2002/0165440	A1	11/2002	Mason et al.	2006/0211923	A1	9/2006	Al-Ali et al.
2002/0183819	A1	12/2002	Struble	2006/0211924	A1	9/2006	Smith et al.
2003/0045784	A1	3/2003	Palatnik et al.	2006/0211925	A1	9/2006	Lamego et al.
2003/0045785	A1	3/2003	Diab et al.	2006/0211932	A1	9/2006	Al-Ali et al.
2003/0049232	A1	3/2003	Page et al.	2006/0226992	A1	10/2006	Al-Ali et al.
2003/0109775	A1	6/2003	O'Neil et al.	2006/0229509	A1	10/2006	Al-Ali et al.
2003/0116769	A1	6/2003	Song et al.	2006/0238358	A1	10/2006	Al-Ali et al.
2003/0117296	A1	6/2003	Seely	2006/0241358	A1	10/2006	Al-Ali et al.
2003/0120160	A1	6/2003	Yarita	2006/0241363	A1	10/2006	Al-Ali et al.
2003/0120164	A1	6/2003	Nielsen et al.	2006/0264718	A1	11/2006	Ruchti et al.
2003/0135099	A1	7/2003	Al-Ali	2007/0078311	A1	4/2007	Al-Ali et al.
2003/0139657	A1	7/2003	Solenberger	2007/0149864	A1	6/2007	Laakkonen
2003/0160257	A1	8/2003	Bader et al.	2007/0185397	A1	8/2007	Govari et al.
2003/0195402	A1	10/2003	Fein et al.	2007/0282478	A1	12/2007	Al-Ali et al.
2004/0006261	A1	1/2004	Swedlow et al.	2009/0247984	A1	10/2009	Lamego et al.
2004/0033618	A1	2/2004	Haass et al.	2009/0275844	A1	11/2009	Al-Ali
2004/0034898	A1	2/2004	Bruegl	2009/0299157	A1	12/2009	Telfort et al.
2004/0059209	A1	3/2004	Al-Ali et al.	2010/0004518	A1	1/2010	Vo et al.
2004/0064259	A1	4/2004	Haaland et al.	2010/0030040	A1	2/2010	Poeze et al.
2004/0081621	A1	4/2004	Arndt et al.	2010/0069725	A1	3/2010	Al-Ali
2004/0092805	A1	5/2004	Yarita	2010/0261979	A1	10/2010	Kiani
2004/0097797	A1	5/2004	Porges et al.	2010/0317936	A1	12/2010	Al-Ali et al.
2004/0133087	A1	7/2004	Ali et al.	2011/0001605	A1	1/2011	Kiani et al.
2004/0138538	A1	7/2004	Stetson	2011/0009719	A1	1/2011	Al-Ali et al.
2004/0138540	A1	7/2004	Baker, Jr. et al.	2011/0082711	A1	4/2011	Poeze et al.
2004/0147822	A1	7/2004	Al-Ali et al.	2011/0105854	A1	5/2011	Kiani et al.
2004/0147823	A1	7/2004	Kiani et al.	2011/0125060	A1	5/2011	Telfort et al.
2004/0158132	A1	8/2004	Zaleski	2011/0172967	A1	7/2011	Al-Ali et al.
2004/0158134	A1	8/2004	Diab et al.	2011/0208015	A1	8/2011	Welch et al.
2004/0158135	A1	8/2004	Baker, Jr. et al.	2011/0209915	A1	9/2011	Telfort et al.
2004/0158162	A1	8/2004	Narimatsu	2011/0213212	A1	9/2011	Al-Ali
2004/0162472	A1	8/2004	Berson et al.	2011/0230733	A1	9/2011	Al-Ali
2004/0167382	A1	8/2004	Gardner et al.	2011/0237911	A1	9/2011	Lamego et al.
2004/0171940	A1	9/2004	Narimatsu	2011/0237914	A1	9/2011	Lamego
2004/0176670	A1	9/2004	Takamura et al.	2011/0237969	A1	9/2011	Eckerbom et al.
2004/0181134	A1	9/2004	Baker, Jr. et al.	2011/0288383	A1	11/2011	Diab
2004/0199063	A1	10/2004	O'Neil et al.	2012/0041316	A1	2/2012	Al Ali et al.
2004/0204639	A1	10/2004	Casciani et al.	2012/0046530	A1	2/2012	Al-Ali
2004/0204868	A1	10/2004	Maynard et al.	2012/0046557	A1	2/2012	Kiani
2004/0229391	A1	11/2004	Ohya et al.	2012/0059267	A1	3/2012	Lamego et al.
2004/0262046	A1	12/2004	Simond et al.	2012/0088984	A1	4/2012	Al-Ali et al.
2004/0267103	A1	12/2004	Li et al.	2012/0116175	A1	5/2012	Al-Ali et al.
2004/0267140	A1	12/2004	Ito et al.	2012/0161970	A1	6/2012	Al-Ali
2005/0011488	A1	1/2005	Doucet	2012/0165629	A1	6/2012	Merritt et al.
2005/0033128	A1	2/2005	Ali et al.	2012/0179006	A1	7/2012	Jansen et al.
2005/0043902	A1	2/2005	Haaland et al.	2012/0209082	A1	8/2012	Al-Ali
2005/0049469	A1	3/2005	Aoyagi et al.	2012/0209084	A1	8/2012	Olsen et al.
2005/0054908	A1	3/2005	Blank et al.	2012/0227739	A1	9/2012	Kiani
2005/0070773	A1	3/2005	Chin et al.	2012/0232359	A1	9/2012	Al-Ali et al.
2005/0070775	A1	3/2005	Chin et al.	2012/0232363	A1	9/2012	Al-Ali et al.
2005/0075546	A1	4/2005	Samsoondar et al.	2012/0265039	A1	10/2012	Kiani
2005/0085704	A1	4/2005	Schulz et al.	2012/0283524	A1	11/2012	Kiani et al.
2005/0085735	A1	4/2005	Baker et al.	2012/0286955	A1	11/2012	Welch et al.
2005/0115561	A1	6/2005	Stahmann et al.	2012/0296178	A1	11/2012	Lamego et al.
2005/0124871	A1	6/2005	Baker et al.	2012/0319816	A1	12/2012	Al-Ali
2005/0143634	A1	6/2005	Baker, Jr. et al.	2012/0330112	A1	12/2012	Lamego et al.
				2013/0006076	A1	1/2013	McHale et al.
				2013/0023775	A1	1/2013	Lamego et al.
				2013/0041591	A1	2/2013	Lamego
				2013/0045685	A1	2/2013	Kiani

(56)

References Cited

U.S. PATENT DOCUMENTS

2013/0046204	A1	2/2013	Lamego et al.	2014/0288400	A1	9/2014	Diab et al.
2013/0060108	A1	3/2013	Schurman et al.	2014/0296664	A1	10/2014	Bruinsma et al.
2013/0060147	A1	3/2013	Welch et al.	2014/0303520	A1	10/2014	Telfort et al.
2013/0079610	A1	3/2013	Al-Ali	2014/0309506	A1	10/2014	Lamego
2013/0096405	A1	4/2013	Garfio	2014/0309559	A1	10/2014	Telfort et al.
2013/0096936	A1	4/2013	Sampath et al.	2014/0316217	A1	10/2014	Purdon et al.
2013/0109935	A1	5/2013	Al-Ali et al.	2014/0316218	A1	10/2014	Purdon et al.
2013/0162433	A1	6/2013	Muhsin et al.	2014/0316228	A1	10/2014	Blank et al.
2013/0178749	A1	7/2013	Lamego	2014/0323825	A1	10/2014	Al-Ali et al.
2013/0190581	A1	7/2013	Al-Ali et al.	2014/0323897	A1	10/2014	Brown et al.
2013/0197328	A1	8/2013	Diab et al.	2014/0323898	A1	10/2014	Purdon et al.
2013/0211214	A1	8/2013	Olsen	2014/0330092	A1	11/2014	Al-Ali et al.
2013/0243021	A1	9/2013	Siskavich	2014/0330098	A1	11/2014	Merritt et al.
2013/0253334	A1	9/2013	Al-Ali et al.	2014/0330099	A1	11/2014	Al-Ali et al.
2013/0267804	A1	10/2013	Al-Ali	2014/0333440	A1	11/2014	Kiani
2013/0274571	A1	10/2013	Diab et al.	2014/0336481	A1	11/2014	Shakespeare et al.
2013/0274572	A1	10/2013	Al-Ali et al.	2014/0343436	A1	11/2014	Kiani
2013/0296672	A1	11/2013	O'Neil et al.	2014/0357966	A1	12/2014	Al-Ali et al.
2013/0296713	A1	11/2013	Al-Ali et al.	2015/0005600	A1	1/2015	Blank et al.
2013/0317370	A1	11/2013	Dalvi et al.	2015/0011907	A1	1/2015	Purdon et al.
2013/0324808	A1	12/2013	Al-Ali et al.	2015/0012231	A1	1/2015	Poeze et al.
2013/0324817	A1	12/2013	Diab	2015/0025406	A1	1/2015	Al-Ali
2013/0331660	A1	12/2013	Al-Ali et al.	2015/0032029	A1	1/2015	Al-Ali et al.
2013/0331670	A1	12/2013	Kiani	2015/0038859	A1	2/2015	Dalvi et al.
2013/0338461	A1	12/2013	Lamego et al.	2015/0045637	A1	2/2015	Dalvi
2014/0012100	A1	1/2014	Al-Ali et al.	2015/0051462	A1	2/2015	Olsen
2014/0025306	A1	1/2014	Weber et al.	2015/0080754	A1	3/2015	Purdon et al.
2014/0034353	A1	2/2014	Al-Ali et al.	2015/0087936	A1	3/2015	Al-Ali et al.
2014/0051952	A1	2/2014	Reichgott et al.	2015/0087938	A1	3/2015	Al-Ali
2014/0051953	A1	2/2014	Lamego et al.	2015/0094546	A1	4/2015	Al-Ali
2014/0051954	A1	2/2014	Al-Ali et al.	2015/0097701	A1	4/2015	Al-Ali et al.
2014/0058230	A1	2/2014	Abdul-Hafiz et al.	2015/0099950	A1	4/2015	Al-Ali et al.
2014/0066783	A1	3/2014	Kiani et al.	2015/0099951	A1	4/2015	Al-Ali et al.
2014/0077956	A1	3/2014	Sampath et al.	2015/0099955	A1	4/2015	Al-Ali et al.
2014/0081097	A1	3/2014	Al-Ali et al.	2015/0101844	A1	4/2015	Al-Ali et al.
2014/0081100	A1	3/2014	Muhsin et al.	2015/0106121	A1	4/2015	Muhsin et al.
2014/0081175	A1	3/2014	Telfort	2015/0112151	A1	4/2015	Muhsin et al.
2014/0094667	A1	4/2014	Schurman et al.	2015/0116076	A1	4/2015	Al-Ali et al.
2014/0100434	A1	4/2014	Diab et al.	2015/0126830	A1	5/2015	Schurman et al.
2014/0114199	A1	4/2014	Lamego et al.	2015/0133755	A1	5/2015	Smith et al.
2014/0120564	A1	5/2014	Workman et al.	2015/0141781	A1	5/2015	Weber et al.
2014/0121482	A1	5/2014	Merritt et al.	2015/0165312	A1	6/2015	Kiani
2014/0121483	A1	5/2014	Kiani	2015/0196237	A1	7/2015	Lamego
2014/0125495	A1	5/2014	Al-Ali	2015/0201874	A1	7/2015	Diab
2014/0127137	A1	5/2014	Bellott et al.	2015/0208966	A1	7/2015	Al-Ali
2014/0128696	A1	5/2014	Al-Ali	2015/0216459	A1	8/2015	Al-Ali et al.
2014/0128699	A1	5/2014	Al-Ali et al.	2015/0230755	A1	8/2015	Al-Ali et al.
2014/0129702	A1	5/2014	Lamego et al.	2015/0238722	A1	8/2015	Al-Ali
2014/0135588	A1	5/2014	Al-Ali et al.	2015/0245773	A1	9/2015	Lamego et al.
2014/0142399	A1	5/2014	Al-Ali et al.	2015/0245794	A1	9/2015	Al-Ali
2014/0142401	A1	5/2014	Al-Ali et al.	2015/0257689	A1	9/2015	Al-Ali et al.
2014/0142402	A1	5/2014	Al-Ali et al.	2015/0272514	A1	10/2015	Kiani et al.
2014/0163344	A1	6/2014	Al-Ali	2015/0351697	A1	12/2015	Weber et al.
2014/0163402	A1	6/2014	Lamego et al.	2015/0351704	A1	12/2015	Kiani et al.
2014/0166076	A1	6/2014	Kiani et al.	2015/0359429	A1	12/2015	Al-Ali et al.
2014/0171763	A1	6/2014	Diab	2015/0366472	A1	12/2015	Kiani
2014/0180038	A1	6/2014	Kiani	2015/0366507	A1	12/2015	Blank
2014/0180154	A1	6/2014	Sierra et al.	2015/0374298	A1	12/2015	Al-Ali et al.
2014/0180160	A1	6/2014	Brown et al.	2015/0380875	A1	12/2015	Coverston et al.
2014/0187973	A1	7/2014	Brown et al.	2016/0000362	A1	1/2016	Diab et al.
2014/0194709	A1	7/2014	Al-Ali et al.	2016/0007930	A1	1/2016	Weber et al.
2014/0194711	A1	7/2014	Al-Ali	2016/0029932	A1	2/2016	Al-Ali
2014/0194766	A1	7/2014	Al-Ali et al.	2016/0029933	A1	2/2016	Al-Ali et al.
2014/0200420	A1	7/2014	Al-Ali	2016/0045118	A1	2/2016	Kiani
2014/0200422	A1	7/2014	Weber et al.	2016/0051205	A1	2/2016	Al-Ali et al.
2014/0206963	A1	7/2014	Al-Ali	2016/0058338	A1	3/2016	Schurman et al.
2014/0213864	A1	7/2014	Abdul-Hafiz et al.	2016/0058347	A1	3/2016	Reichgott et al.
2014/0243627	A1	8/2014	Diab et al.	2016/0066823	A1	3/2016	Al-Ali et al.
2014/0266790	A1	9/2014	Al-Ali et al.	2016/0066824	A1	3/2016	Al-Ali et al.
2014/0275808	A1	9/2014	Poeze et al.	2016/0066879	A1	3/2016	Telfort et al.
2014/0275835	A1	9/2014	Lamego et al.	2016/0072429	A1	3/2016	Kiani et al.
2014/0275871	A1	9/2014	Lamego et al.	2016/0081552	A1	3/2016	Wojtczuk et al.
2014/0275872	A1	9/2014	Merritt et al.	2016/0095543	A1	4/2016	Telfort et al.
2014/0275881	A1	9/2014	Lamego et al.	2016/0095548	A1	4/2016	Al-Ali et al.
2014/0276115	A1	9/2014	Dalvi et al.	2016/0103598	A1	4/2016	Al-Ali et al.
				2016/0113527	A1	4/2016	Al-Ali et al.
				2016/0143548	A1	5/2016	Al-Ali

(56)

References Cited

U.S. PATENT DOCUMENTS

2016/0166182 A1 6/2016 Al-Ali
 2016/0296169 A1 10/2016 McHale et al.
 2016/0310052 A1 10/2016 Al-Ali

FOREIGN PATENT DOCUMENTS

EP 0 569 670 2/1993
 EP 0 675 540 10/1995
 EP 0 675 541 10/1995
 EP 0469395 B1 2/1996
 EP 0417447 B1 10/1997
 EP 0606356 B1 6/1998
 EP 0734221 B1 7/1998
 EP 0 529 412 11/1998
 EP 1 080 683 3/2001
 EP 1 207 536 5/2002
 EP 1 895 892 5/2010
 EP 2 286 721 2/2011
 EP 2 305 104 4/2011
 EP 2 476 369 A1 7/2012
 EP 2 139 383 2/2013
 EP 2 476 369 B1 10/2014
 JP 61-28172 2/1986
 JP 62-000324 1/1987
 JP 63-275327 11/1988
 JP 64-500495 2/1989
 JP 2-126829 5/1990
 JP 2-145457 12/1990
 JP 05-200017 8/1993
 JP 05-207993 8/1993
 JP H06-178776 6/1994
 JP 6-505903 7/1994
 JP 6-237013 8/1994
 JP H07-391 1/1995
 JP H07-171089 7/1995
 JP H07-171090 7/1995
 JP 7-281618 10/1995
 JP 07-325546 12/1995
 JP 09-108203 4/1997
 JP 9-192120 7/1997
 JP 09-308623 12/1997
 JP 10-216112 8/1998
 JP 10-509352 9/1998
 JP 10-269344 A 10/1998
 JP 10-295676 11/1998
 JP 10-305026 11/1998
 JP 11-037932 2/1999
 JP 11-163412 6/1999
 JP 11-164826 6/1999
 JP 11-506834 6/1999
 JP 11-183377 7/1999
 JP 2000-116625 4/2000
 JP 2002-516689 6/2002
 JP 2002-228579 8/2002
 JP 2002-525151 8/2002
 JP 2002-315739 10/2002
 JP 2003-507718 2/2003
 JP 2003-084108 3/2003
 JP 2003-521985 7/2003
 JP 2004-070179 3/2004
 JP 2004-173866 6/2004
 JP 2004-226277 8/2004
 JP 2004-296736 10/2004
 JP 2004-532526 10/2004
 JP 2004-327760 11/2004
 JP 2005-501589 1/2005
 JP 2005-253478 9/2005
 JP 4879913 12/2011
 WO WO 88/01150 2/1988
 WO WO 88/02020 2/1988
 WO WO 92/16142 10/1992
 WO WO 93/06776 4/1993
 WO WO 95/16387 6/1995
 WO WO 96/13208 5/1996
 WO WO 96/41138 12/1996

WO WO 97/01985 1/1997
 WO WO 97/29678 8/1997
 WO WO 97/29710 8/1997
 WO WO 98/43071 10/1998
 WO WO 00/18290 4/2000
 WO WO 00/42911 7/2000
 WO WO 00/59374 10/2000
 WO WO 01/13790 3/2001
 WO WO 01/30414 5/2001
 WO WO 01/58347 8/2001
 WO WO 02/17780 3/2002
 WO WO 02/26123 4/2002
 WO WO 02/089664 11/2002
 WO WO 03/020129 3/2003
 WO WO 03/068060 8/2003
 WO WO 03/077761 9/2003
 WO WO 2004/034898 4/2004
 WO WO 2004/038801 5/2004
 WO WO 2005/004712 1/2005
 WO WO 2005/011488 2/2005
 WO WO 2006/017117 2/2006
 WO WO 2006/094107 9/2006
 WO WO 2006/094108 9/2006
 WO WO 2006/094155 9/2006
 WO WO 2006/094168 9/2006
 WO WO 2006/094169 9/2006
 WO WO 2006/094170 9/2006
 WO WO 2006/094171 9/2006
 WO WO 2006/094279 9/2006
 WO WO 2006/115580 11/2006
 WO WO 2009/013835 1/2009
 WO WO 2009/137524 11/2009

OTHER PUBLICATIONS

European Examination Report, re EP App. No. 06 736 798.7, dated Dec. 2, 2015.
 U.S. Appl. No. 14/967,998, filed Dec. 14, 2015, Al-Ali et al.
 U.S. Appl. No. 14/860,294, filed Sep. 21, 2015, Lamego.
 Japanese Office Action (Official Inquiry) re JP App. No. 2007-558246, dated Dec. 11, 2012.
 Japanese Office Action (Reasons for Rejection) re JP App. No. 2007-558246, dated Nov. 1, 2011.
 Japanese Office Action, re JP Application No. 2012-045419, dated Jun. 26, 2012.
 "Medical." 50 Ways to Touch Memory. 3rd ed. Dallas: Dallas Semiconductor Corporation, Aug. 1994: pp. 24-25. Print.
 "Application Note 84 Use of Add-Only Memory for Secure Storage of Monetary Equivalent Data," Dallas Semiconductor, Jun. 22, 1999, in 5 pages.
 Dallas Semiconductor Corp: DS2430A Announcement, retrieved Jun. 10, 1998, in 2 pages. <https://web.archive.org/web/19980610045525/http://dalsemi.com/News_Center/New_Products/1996/2430a.html>.
 European Extended Search Report of European Application No. 12163719.3, mailing date of Jun. 18, 2012, in 6 pages.
 Favennec, J.M. "Smart sensors in industry." J. Phys. E: Sci. Instrum. 20(9): Sep. 1987, pp. 1087-1090.
 Jones, K.L., et al. "A Protocol for Automatic Sensor Detection and Identification in a Wireless Biodevice Network," IEEE, Jun. 1998, 6 pages.
 Schmitt, Joseph M.; Zhou, Guan-Xiong; Miller, Justin, Measurement of Blood Hematocrit by Dual-wavelength Near-IR Photoplethysmography, published May 1992, Proc. SPIE vol. 1641, p. 150-161, Physiological Monitoring and Early Detection Diagnostic Methods, Thomas S. Mang; Ed. (SPIE homepage), in 12 pages.
 Subramanian, S., et al. "Design for Constraint Violation Detection in Safety-Critical Systems," IEEE, Nov. 1998: pp. 1-8.
 Burritt, Mary F.; Current Analytical Approaches to Measuring Blood Analytes; vol. 36; No. 8(B); 1990.
 European Examination Report dated Apr. 1, 2010, re EP App. No. 08 744 412.1-2319.
 European Examination Report dated Mar. 18, 2011, re EP App. No. 08 744 412.1-2319.

(56)

References Cited

OTHER PUBLICATIONS

European Examination Report dated Sep. 2, 2010, re EP App. No. 08 744 412.1-2319.
 European Extended Search Report re EPO App. No. 10162402.1, SR dated Aug. 9, 2010.
 Hall, et al Jeffrey W.; Near-Infrared Spectrophotometry: A New Dimension in Clinical Chemistry; vol. 38; No. 9; 1992.
 Japanese Office Action (Notice of Reasons for Rejection) re JP App. No. 2007-558246, dated Jun. 28, 2011.
 Japanese Office Action re JP Application No. JP 2007-558208, dated Aug. 23, 2011.
 Japanese First Office Action (Notice of Reasons for Rejection), re JP App. No. 2007-558247, dated Jun. 28, 2011.
 Japanese Office Action (Notice of Allowance), re JP App. No. 2007-558247, dated Oct. 24, 2011.
 Japanese Office Action (Notice of Reasons for Rejection), re JP App. No. 2007-558238, dated Jun. 28, 2011.
 Japanese Office Action re JP Application No. JP 2007-558248, dated Nov. 8, 2011.
 Japanese First Office Action (Notice of Reasons for Rejection), re JP App. No. 2007-558207, dated Jun. 28, 2011.
 Japanese Office Action, re JP Application No. 2007-558237, dated Aug. 1, 2011.
 Japanese Office Action re JP Application No. 2007-558209, dated Oct. 25, 2011.
 Japanese Office Action re JP Application No. 2007-558245, dated Oct. 25, 2011.
 Japanese Office Action re JP Application No. 2007-558249, dated Jul. 13, 2011.
 Japanese Office Action re JP Application No. 2007-558249, dated Nov. 8, 2011.
 Kuenstner, et al., J. Todd; Measurement of Hemoglobin in Unlysed Blood by Near-Infrared Spectroscopy; vol. 48; No. 4, 1994.
 Manzke, et al., B., Multi Wavelength Pulse OXimetry in the Measurement of Hemoglobin Fractions; vol. 2676, date unknown.

Naumenko, E. K.; Choice of Wavelengths for Stable Determination of Concentrations of Hemoglobin Derivatives from Absorption Spectra of Erythrocytes; vol. 63; no. 1; pp. 60-66 Jan.-Feb. 1996; Original article submitted Nov. 3, 1994.
 Patent Cooperation Treaty (PCT) International Search Report; PCT/US 2006/007389; Date of Mailing Jul. 17, 2006; pp. 1-9.
 PCT International Search Report; PCT/US2006/007387; Date of Mailing Jul. 17, 2006; pp. 1-9.
 PCT International Search Report; PCT/US2006/007388; Date of Mailing Jul. 17, 2006; pp. 1-9.
 PCT International Search Report; PCT/US2006/007506; Date of Mailing Jul. 17, 2006; pp. 1-10.
 PCT International Search Report; PCT/US2006/007536; Date of Mailing Jul. 17, 2006; pp. 1-9.
 PCT International Search Report; PCT/US2006/007537; Date of Mailing Jul. 17, 2006; pp. 1-10.
 PCT International Search Report; PCT/US2006/007538; Date of Mailing Jul. 17, 2006; pp. 1-9.
 PCT International Search Report; PCT/US2006/007539; Date of Mailing Jul. 17, 2006; pp. 1-9.
 PCT International Search Report; PCT/US2006/007540; Date of Mailing Jul. 17, 2006; pp. 1-9.
 PCT International Search Report; PCT/US2006/007958; Date of Mailing Jul. 17, 2006; pp. 1-8.
 PCT Search Report of International Application No. PCT/US2008/058327, Mailing Date of Aug. 12, 2008, in 12 pages.
 Schmitt, Joseph M.; Simple Photon Diffusion Analysis of the Effects of Multiple Scattering on Pulse Oximetry; Mar. 14, 1991; revised Aug. 30, 1991.
 Schnapp, et al., L.M.; Pulse Oximetry. Uses and Abuses.; Chest 1990; 98; 1244-1250001 10.1378/Chest.98.5.1244.
 U.S. Appl. No. 12/082,810, filed Apr. 14, 2008, Al-Ali.
 U.S. Appl. No. 14/148,462, filed Jan. 6, 2014, Al-Ali et al.
 European Examination Report, re EP App. No. 06 736 798.7, dated Jul. 18, 2016.

* cited by examiner

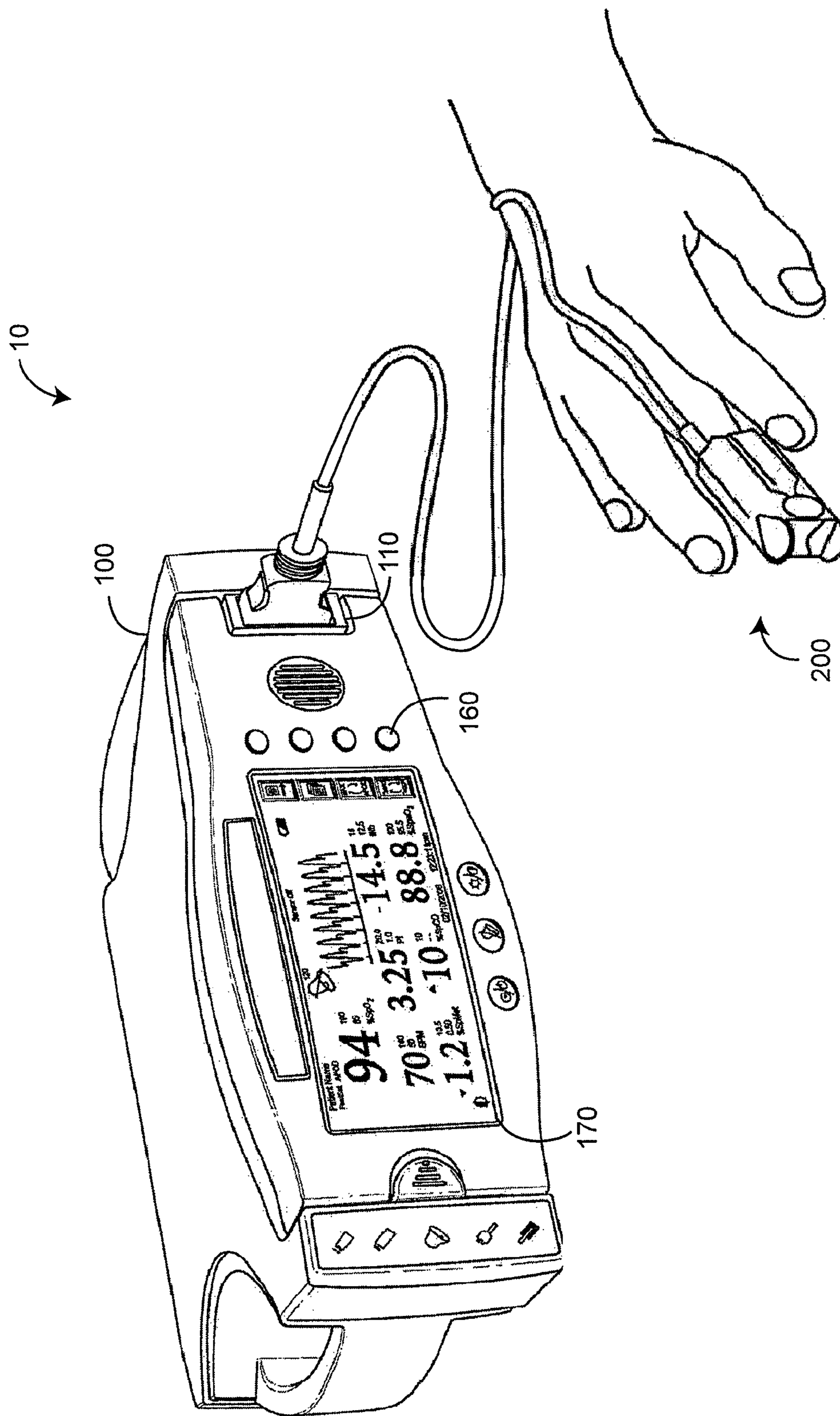


FIG. 1

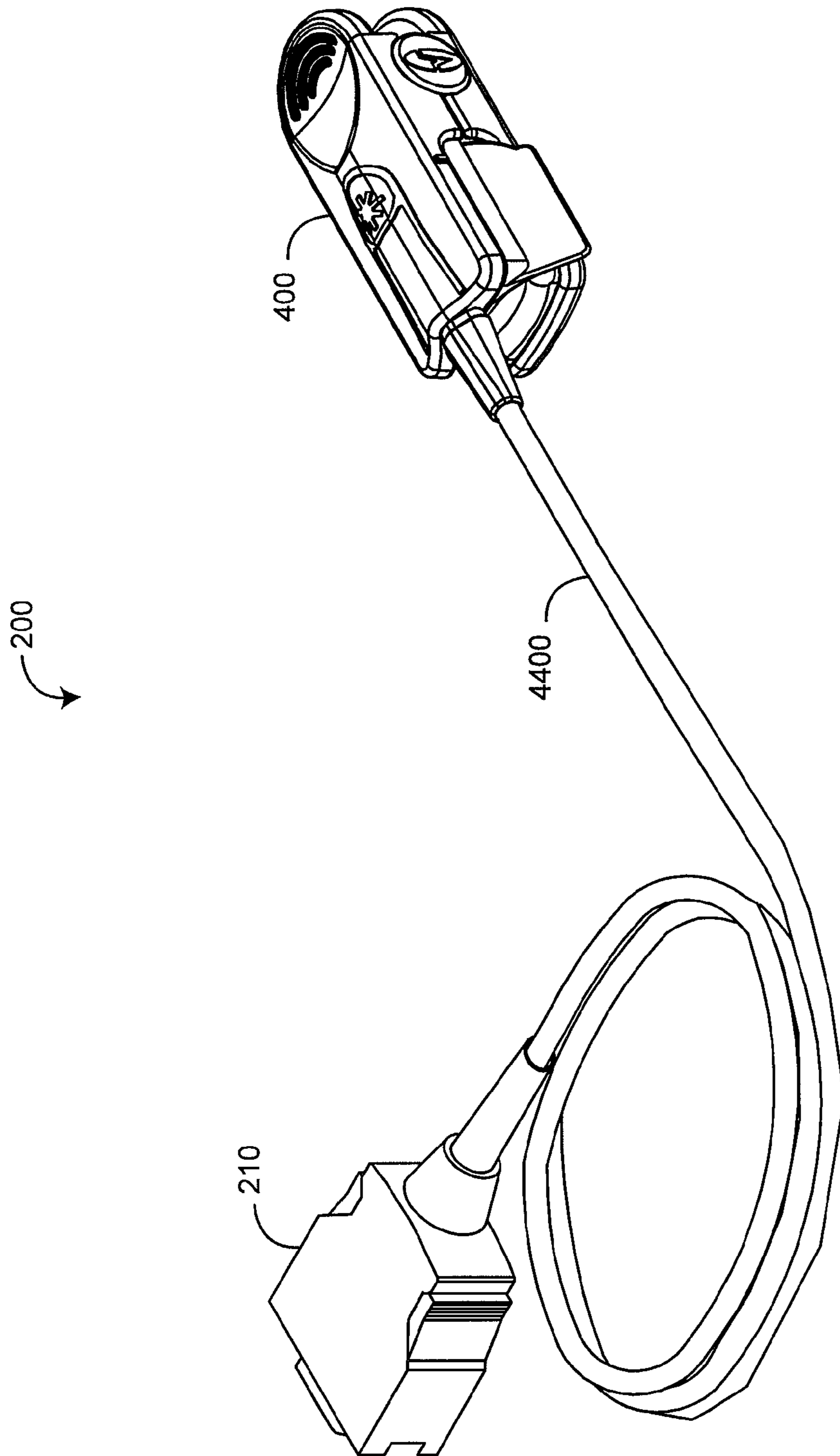


FIG. 2A

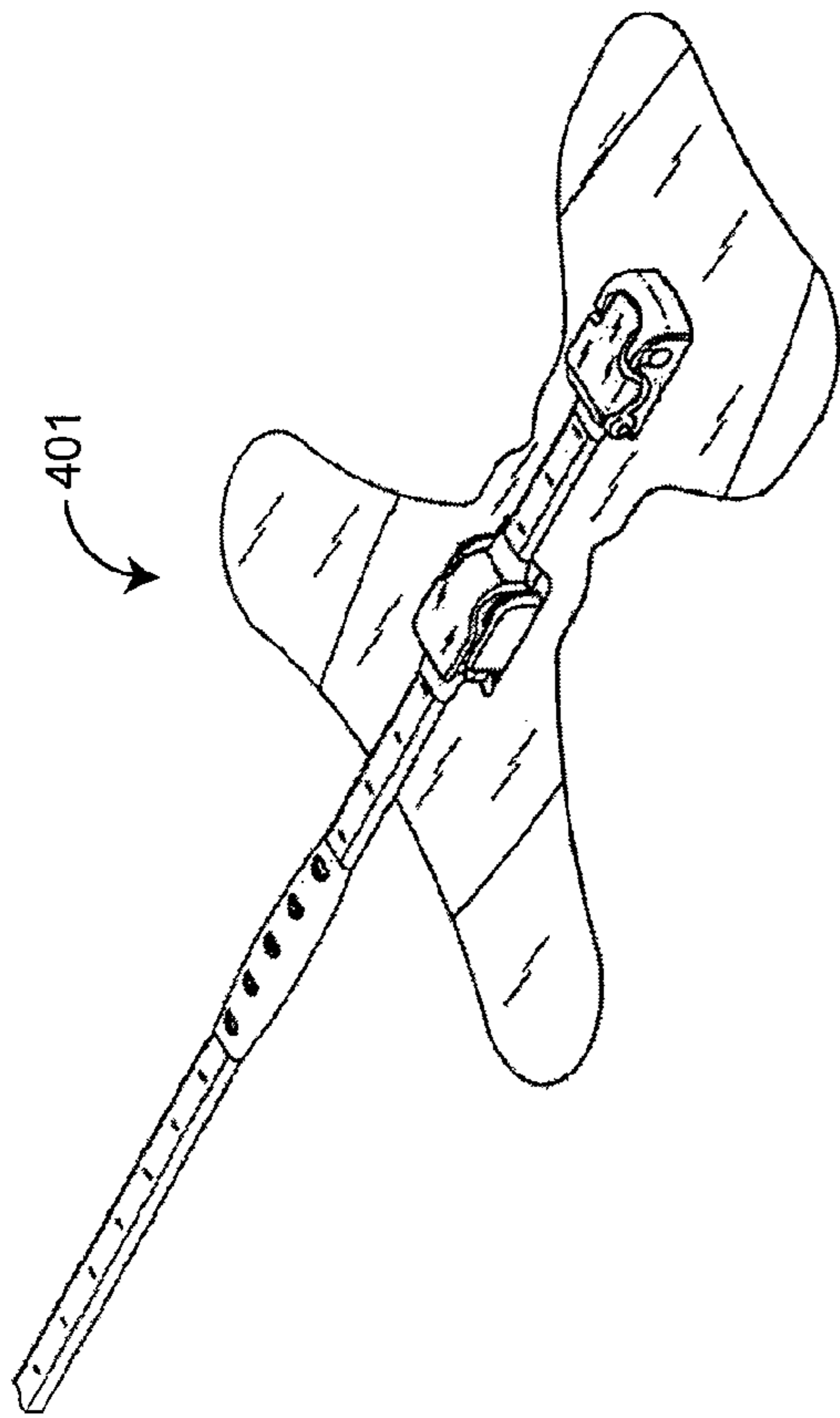


FIG. 2B

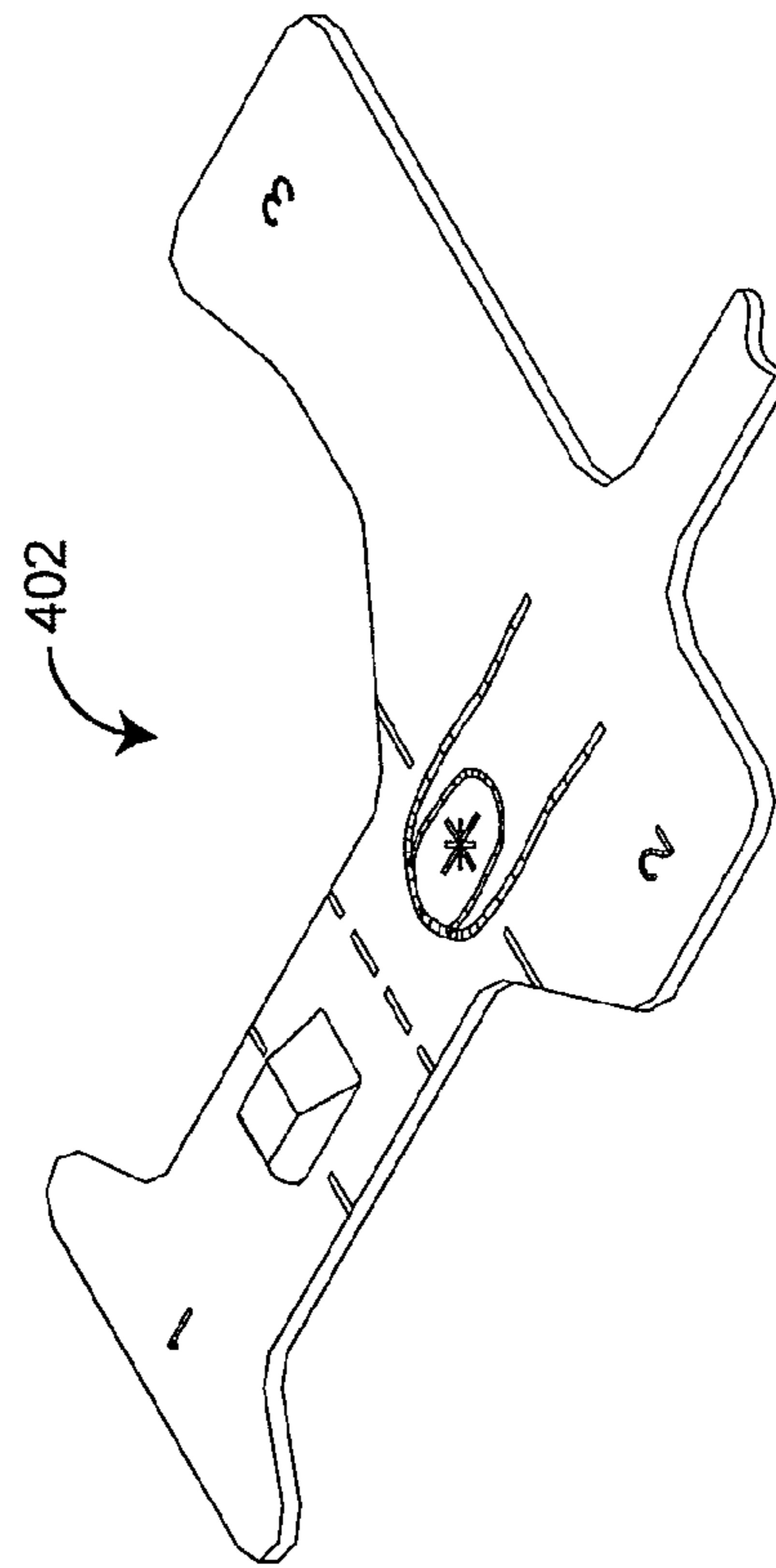


FIG. 2C

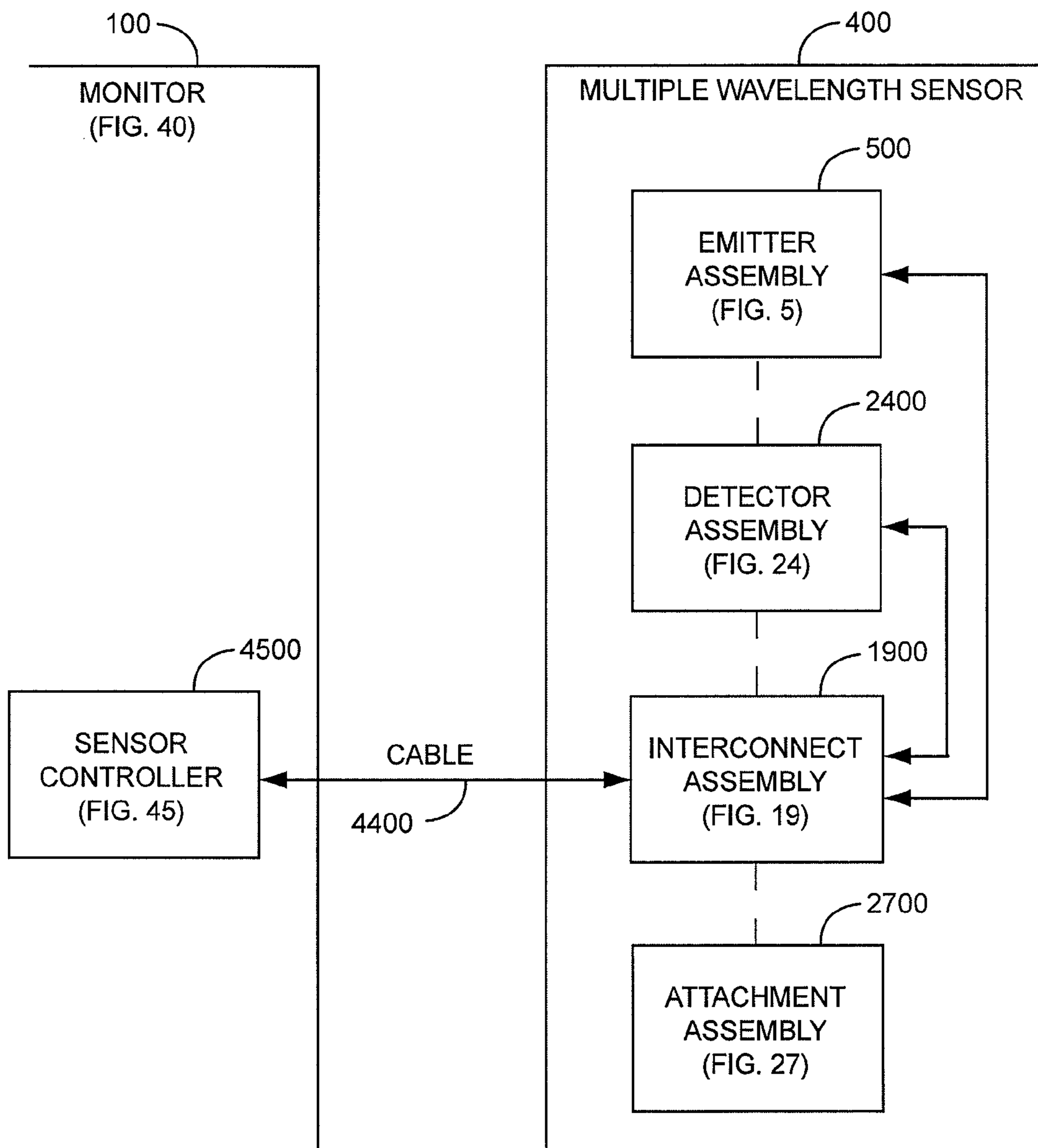


FIG. 3

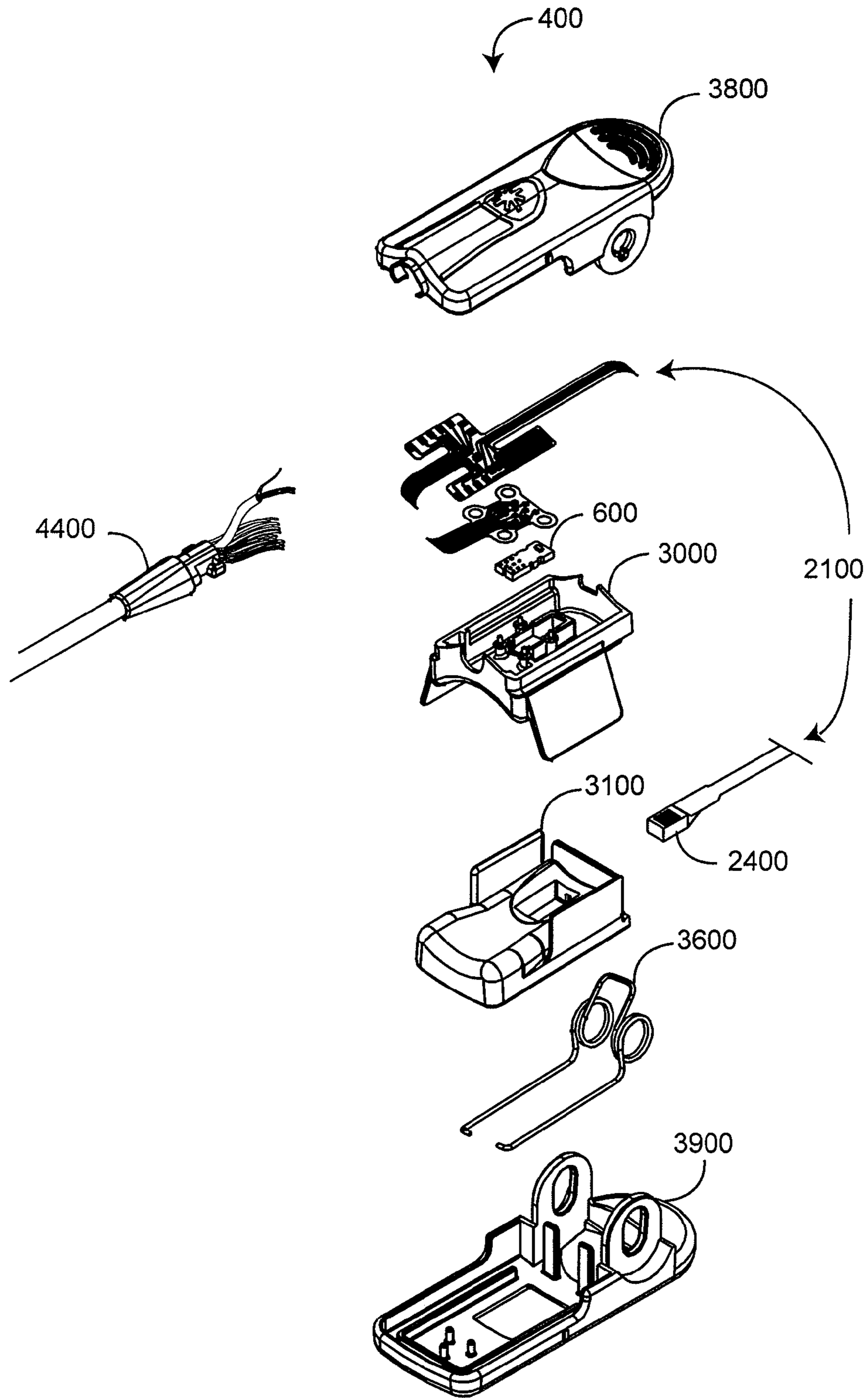


FIG. 4

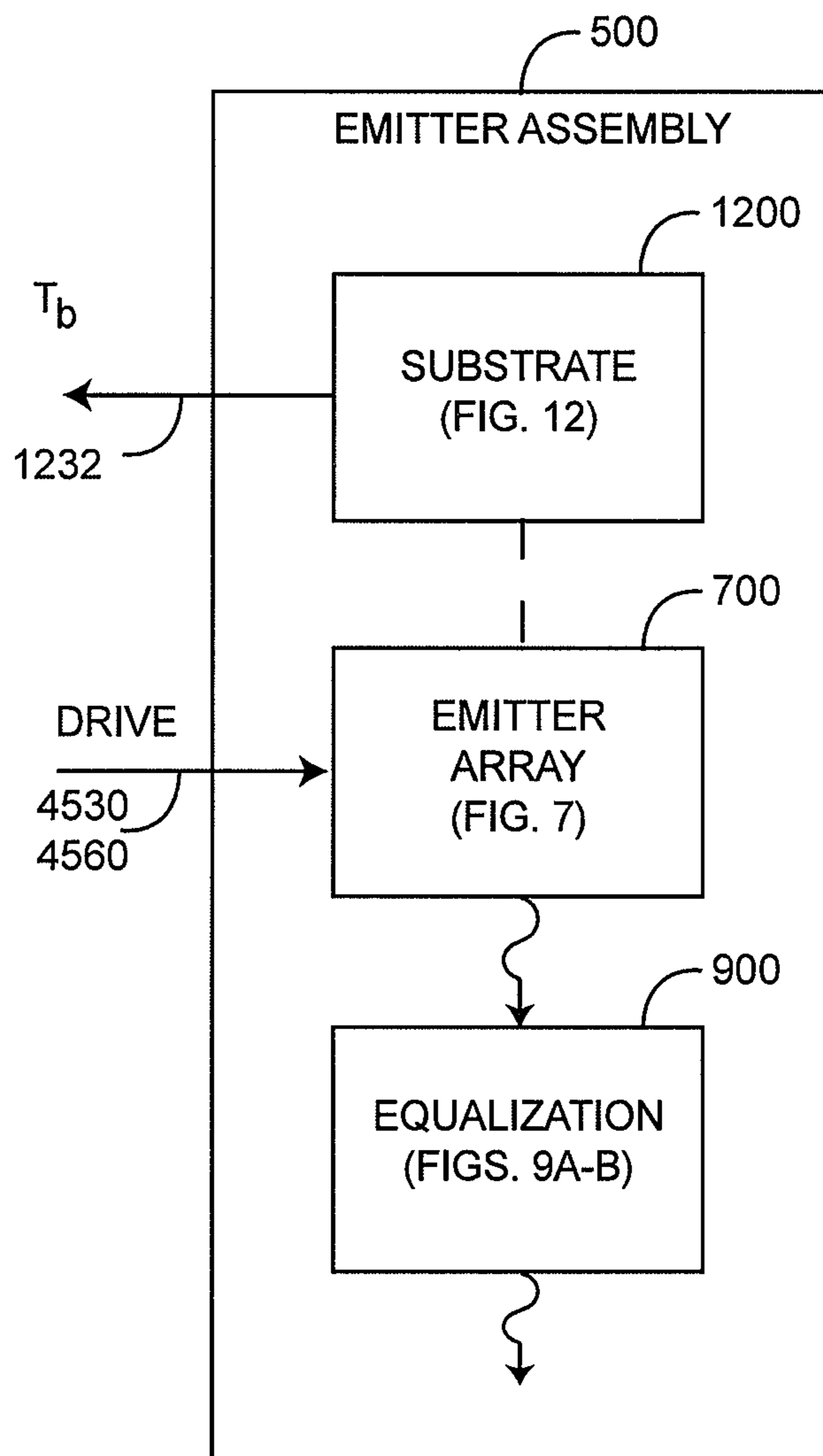


FIG. 5

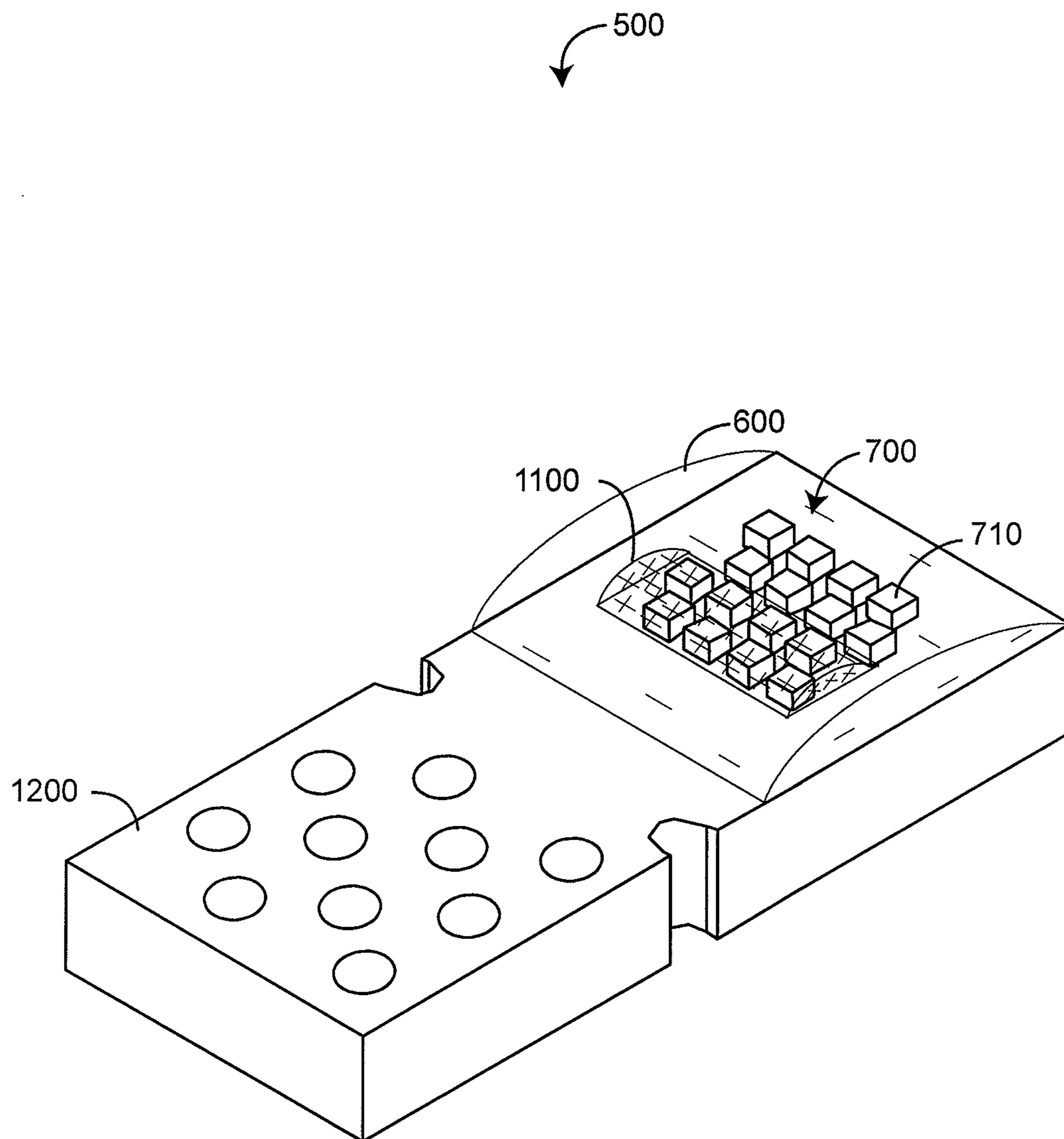


FIG. 6

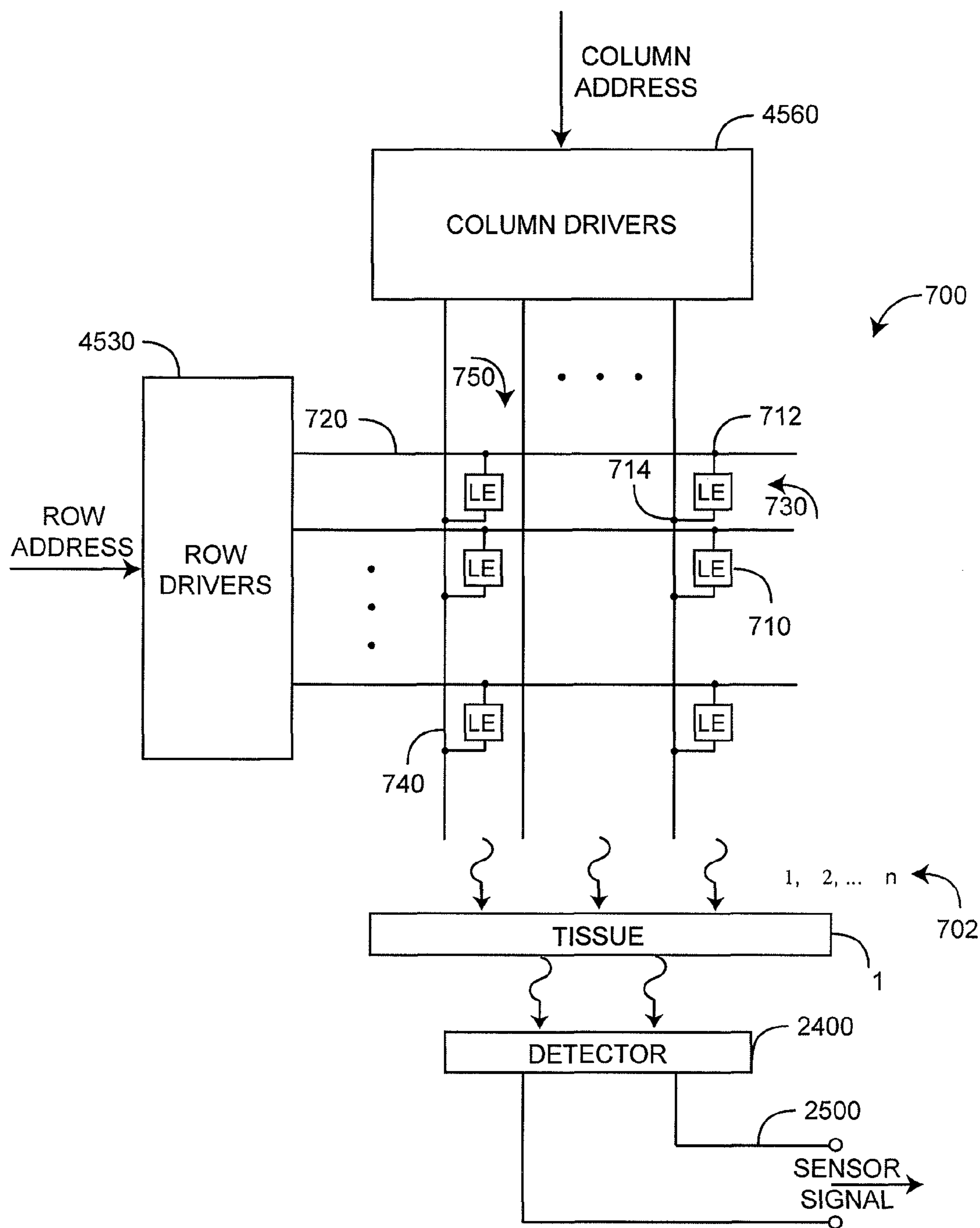


FIG. 7

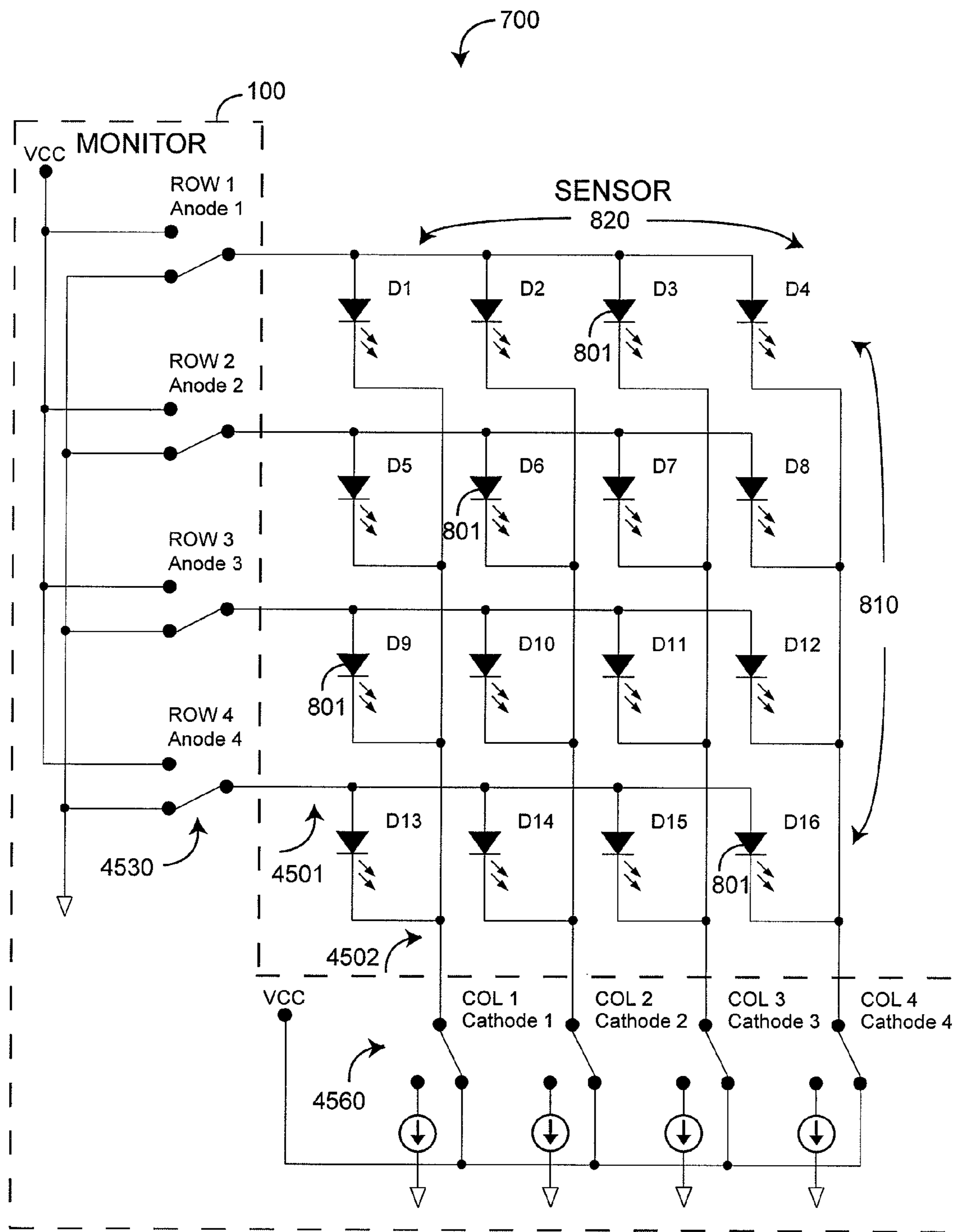


FIG. 8

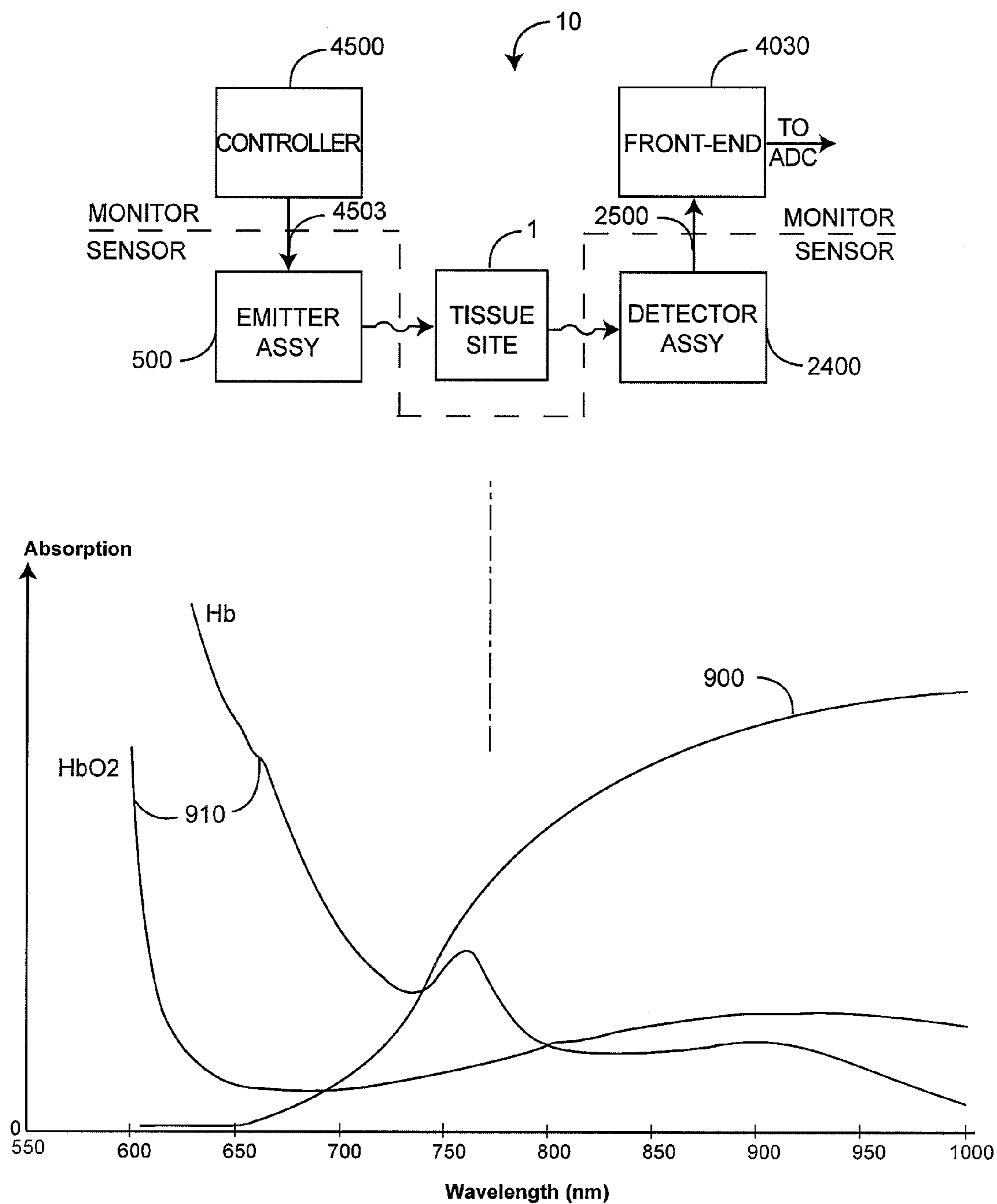


FIG. 9

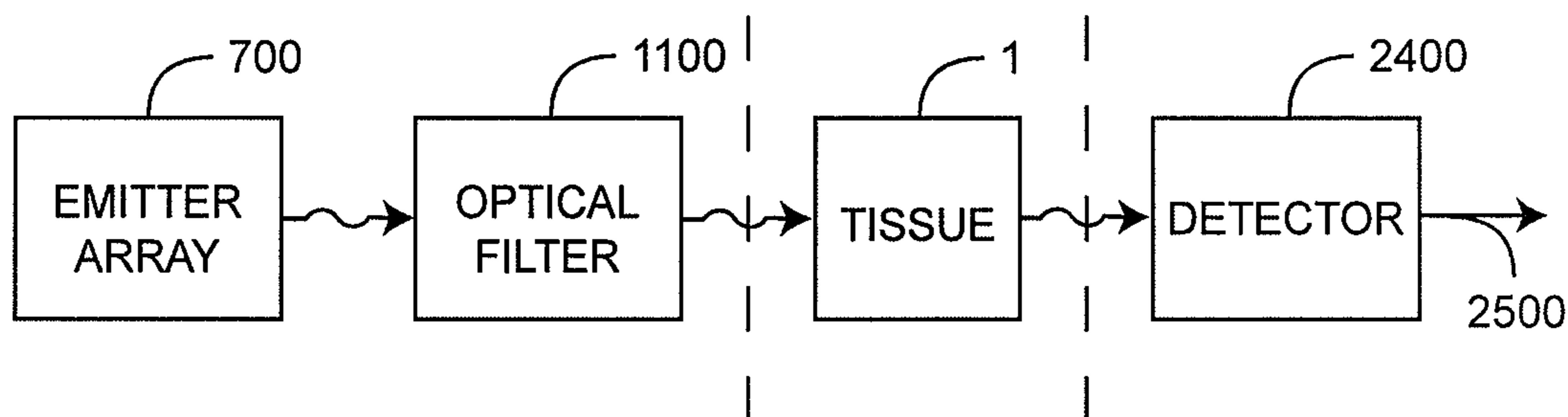


FIG. 10A

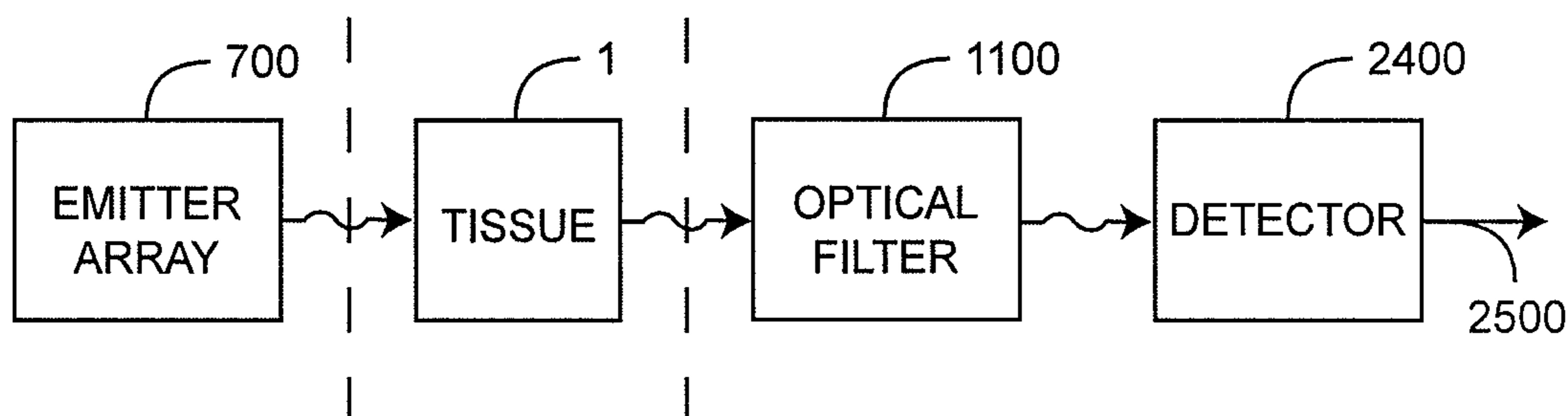


FIG. 10B

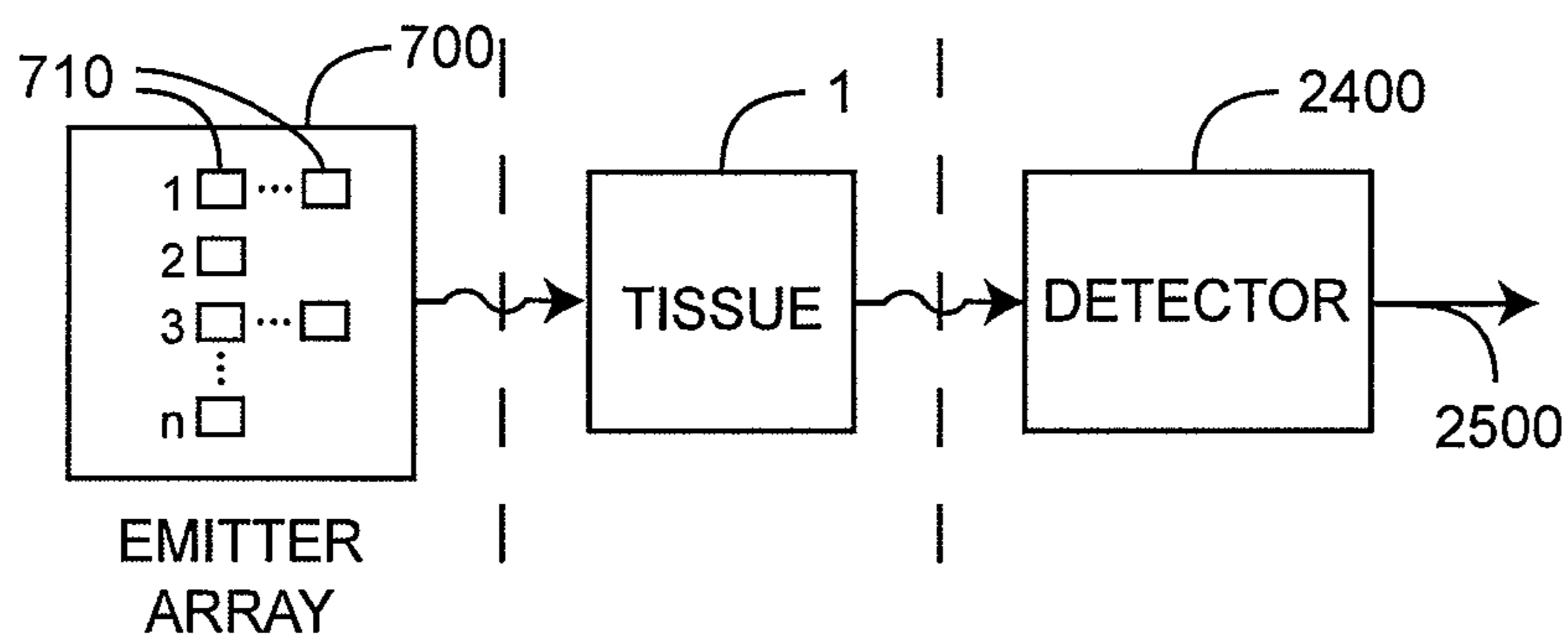


FIG. 10C

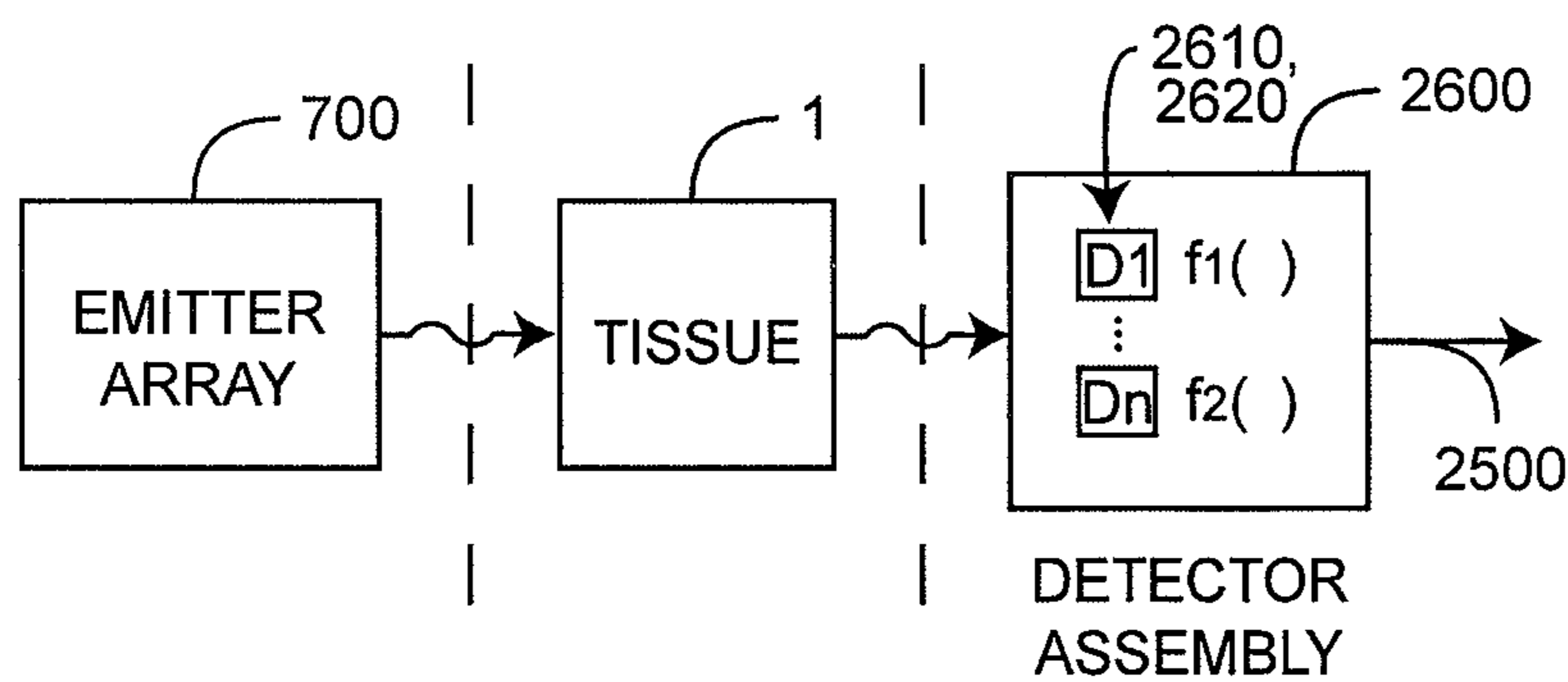


FIG. 10D

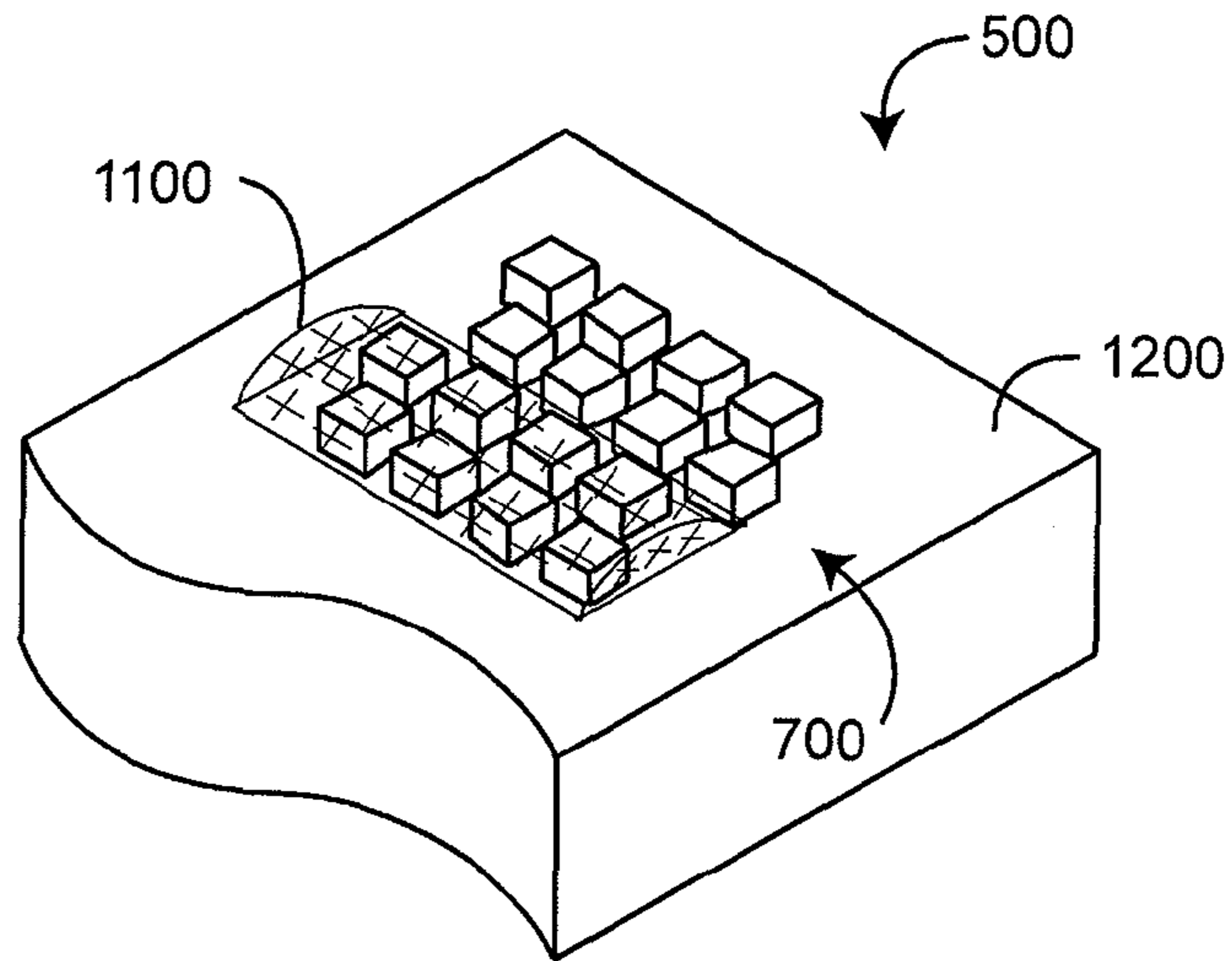


FIG. 11A

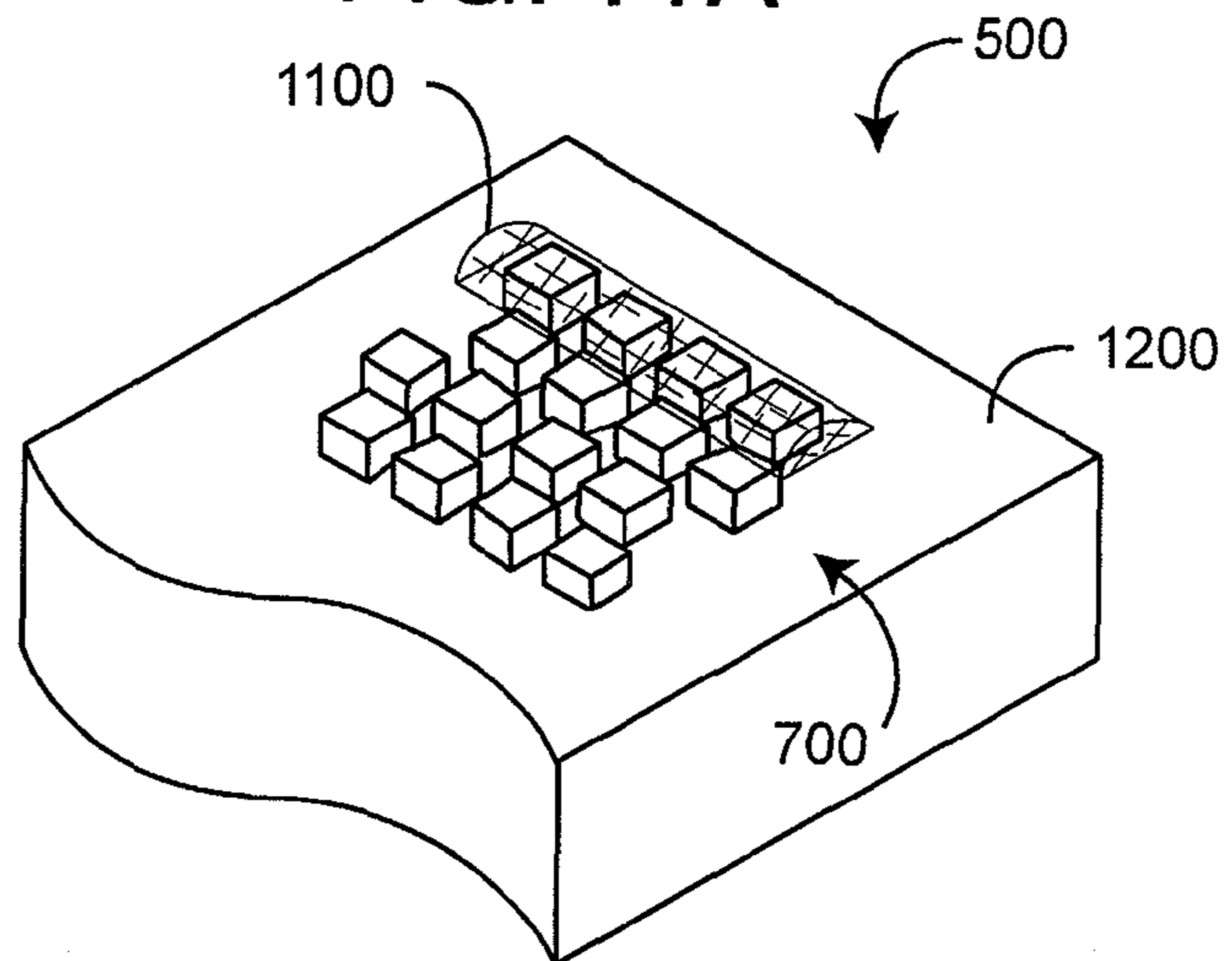


FIG. 11B

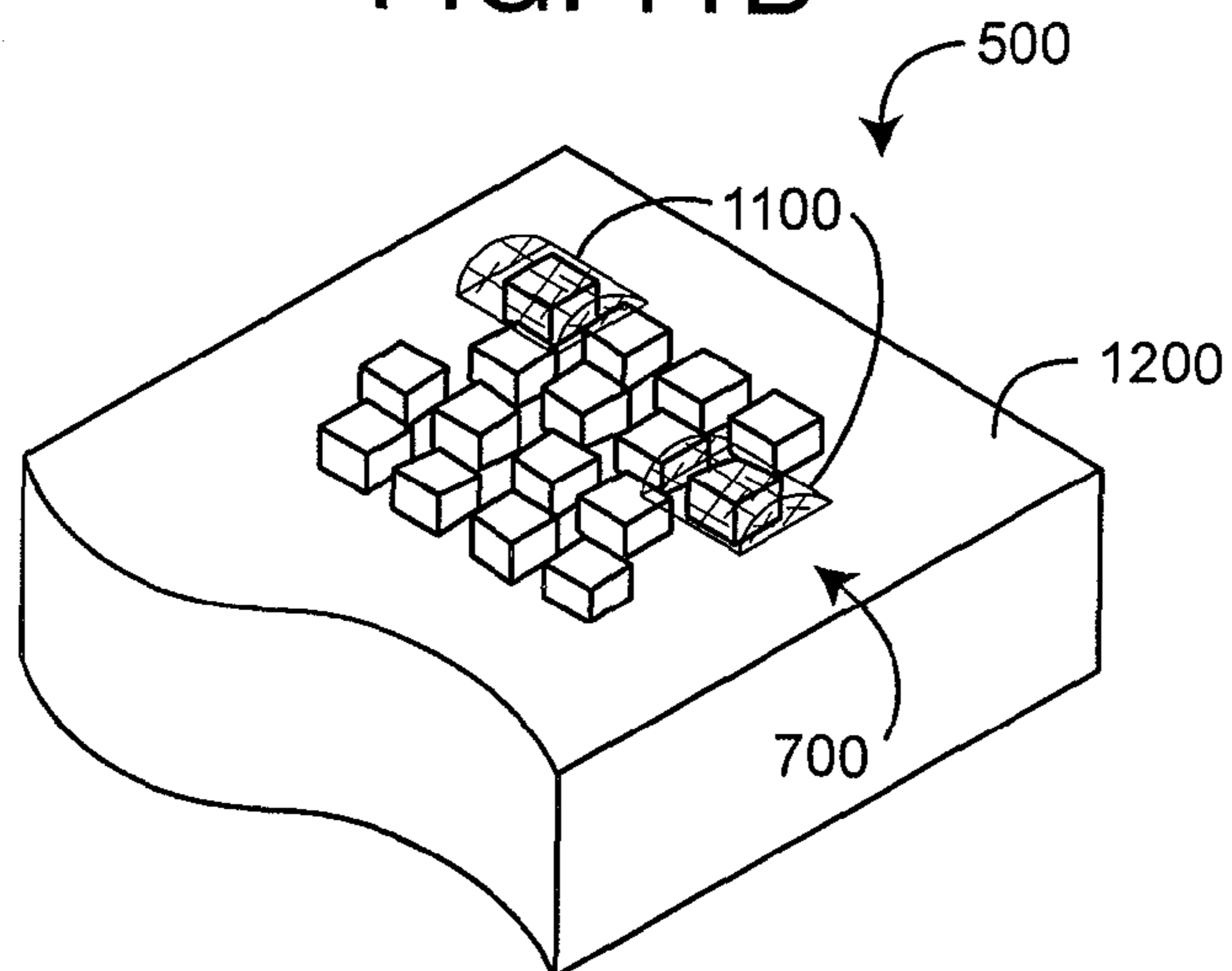


FIG. 11C

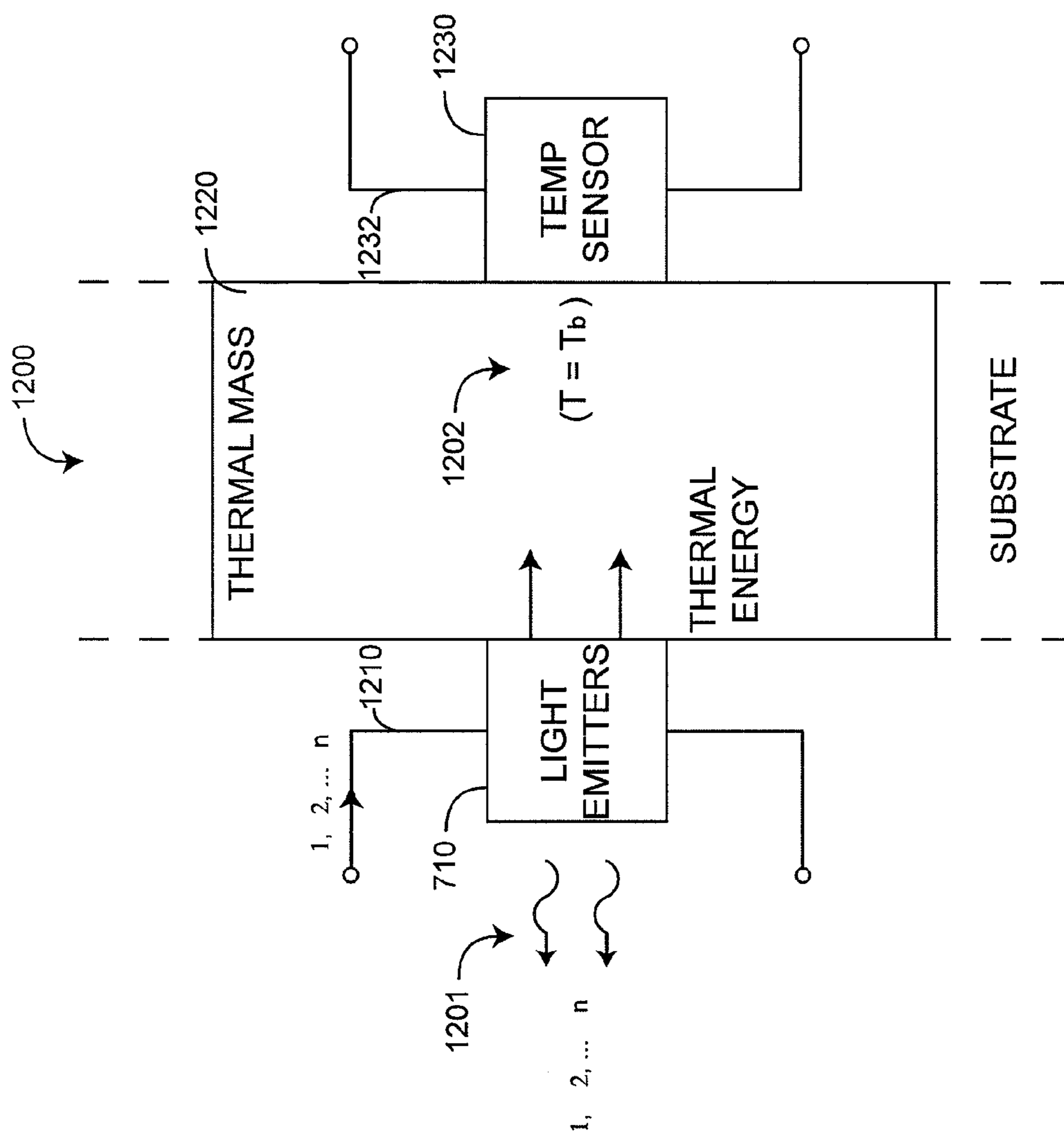


FIG. 12

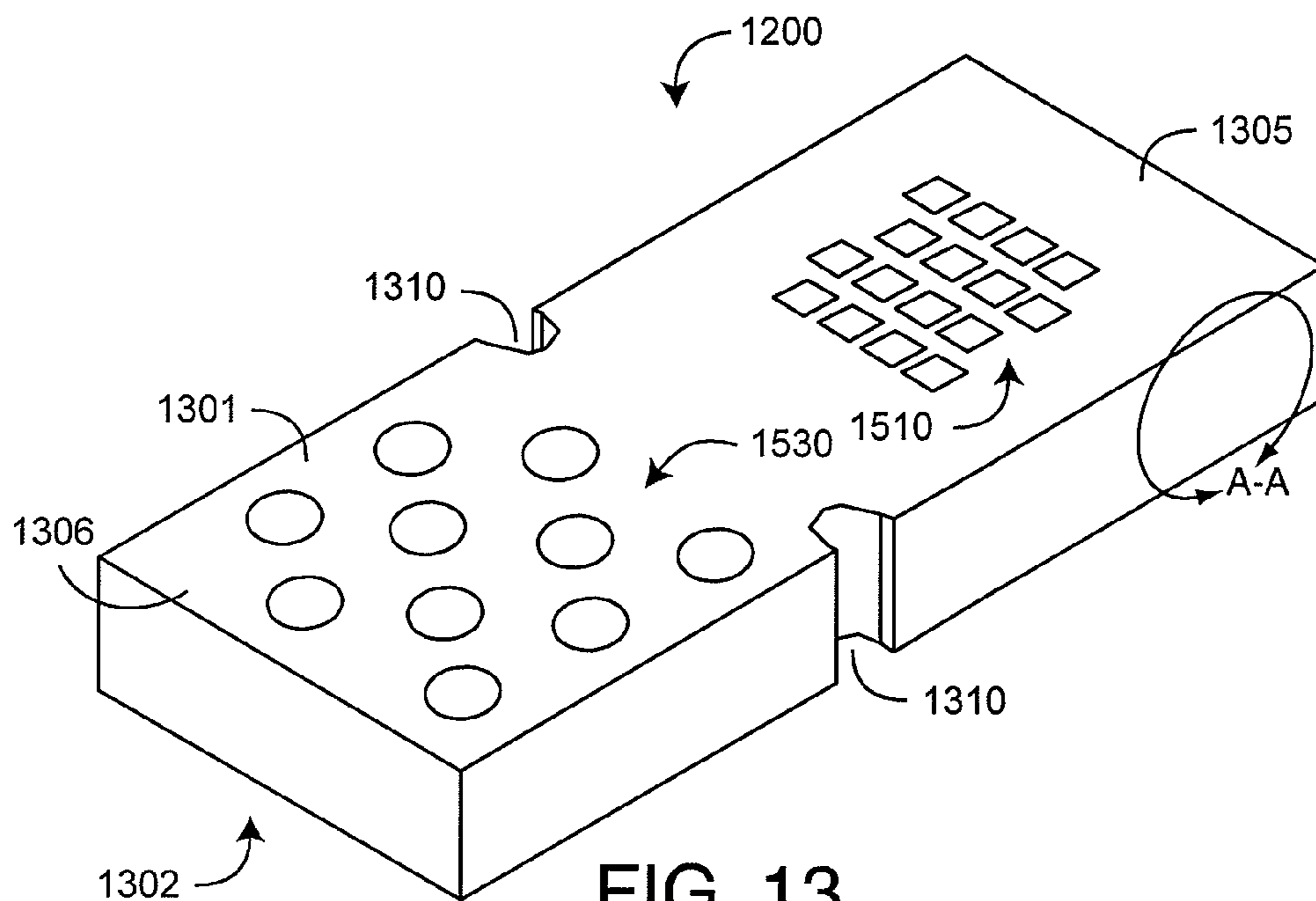


FIG. 13

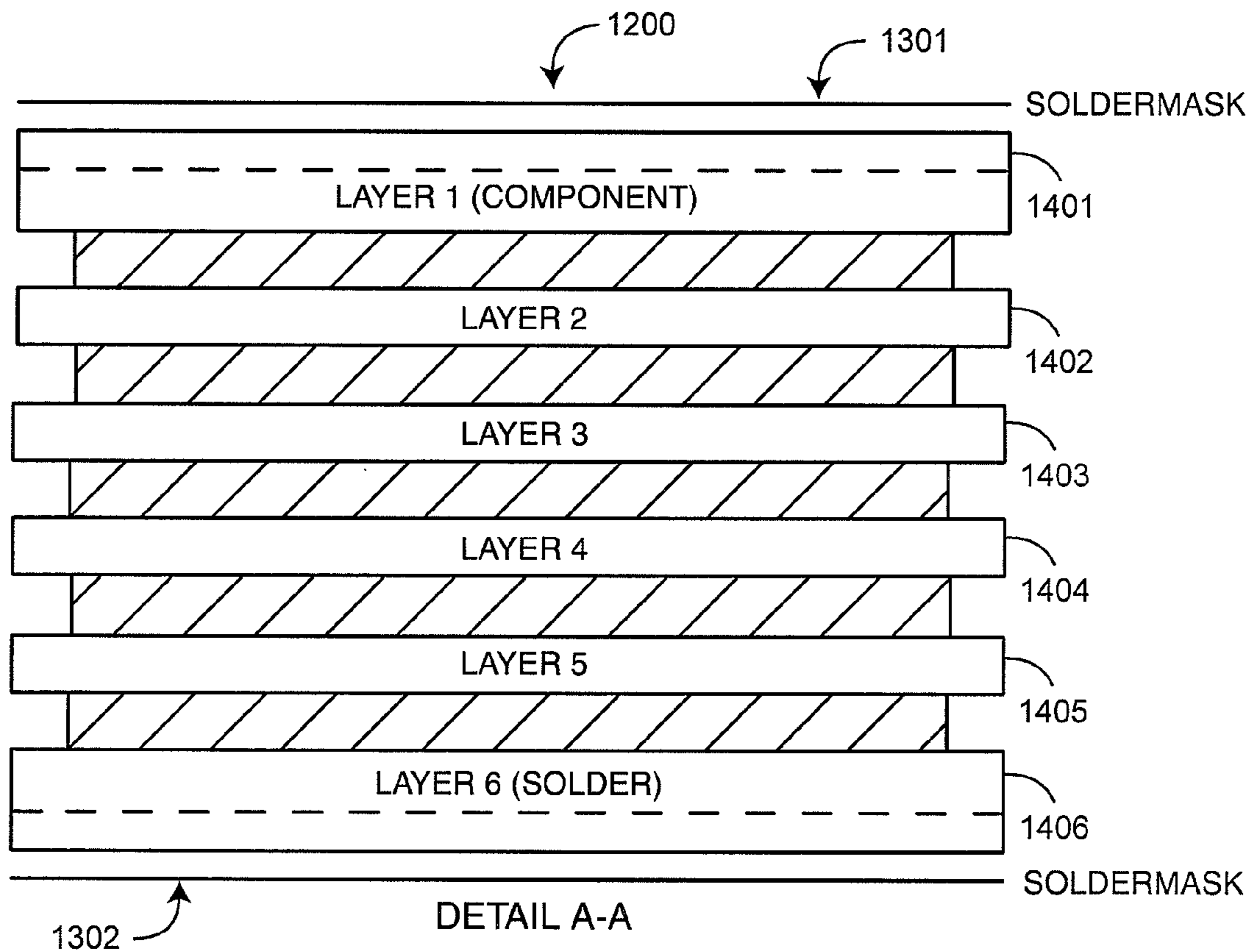


FIG. 14

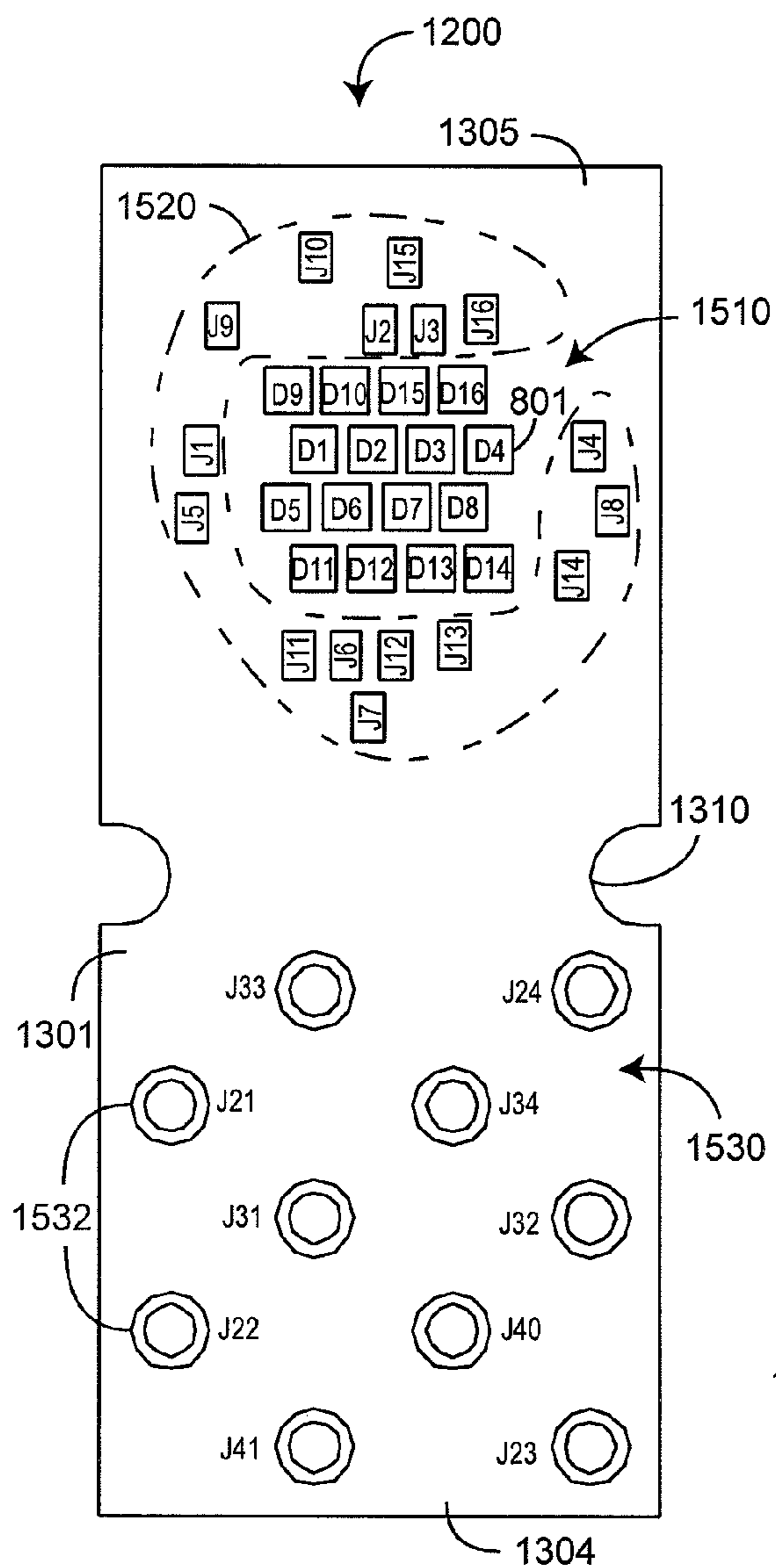


FIG. 15

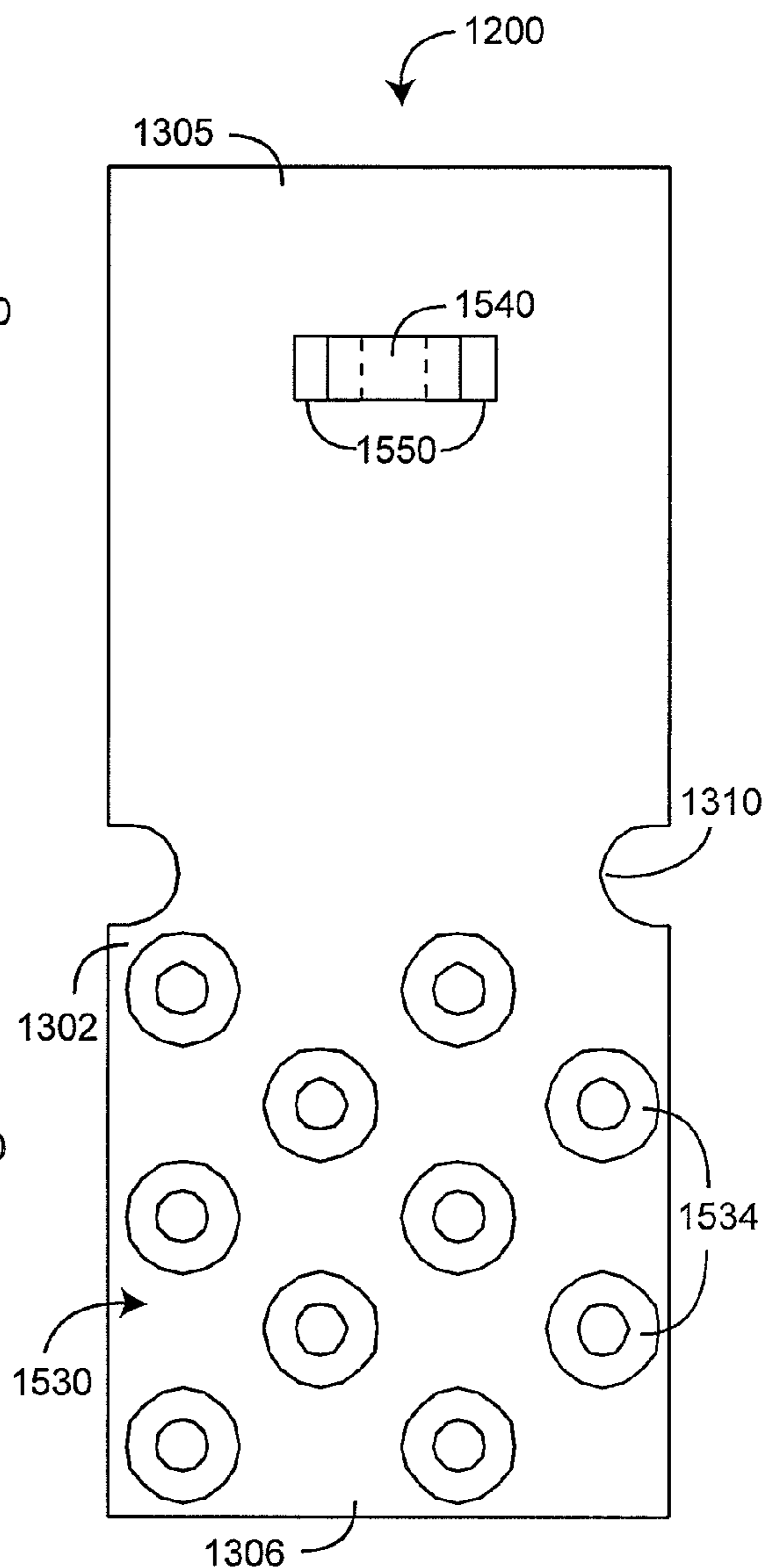


FIG. 16

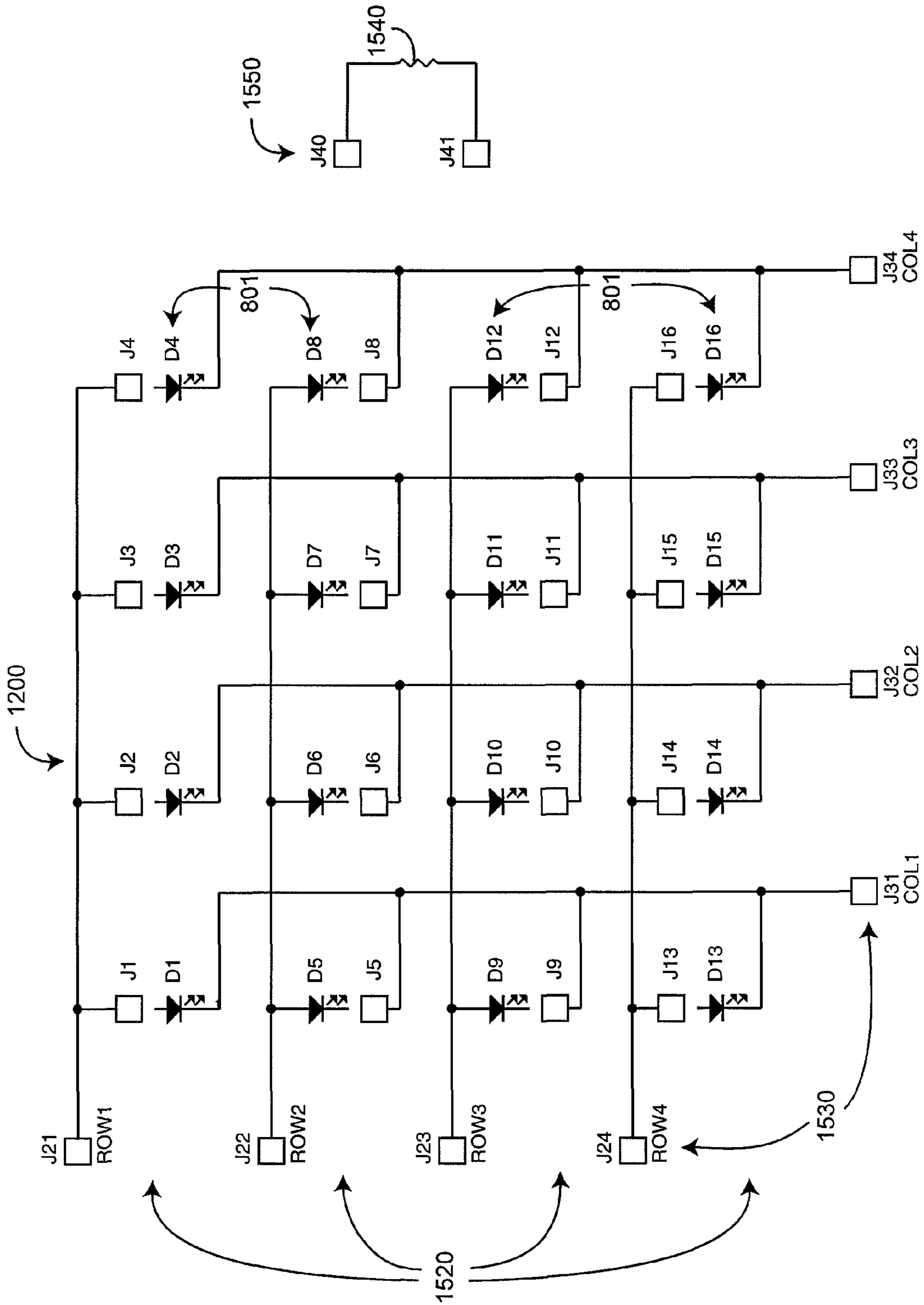


FIG. 17

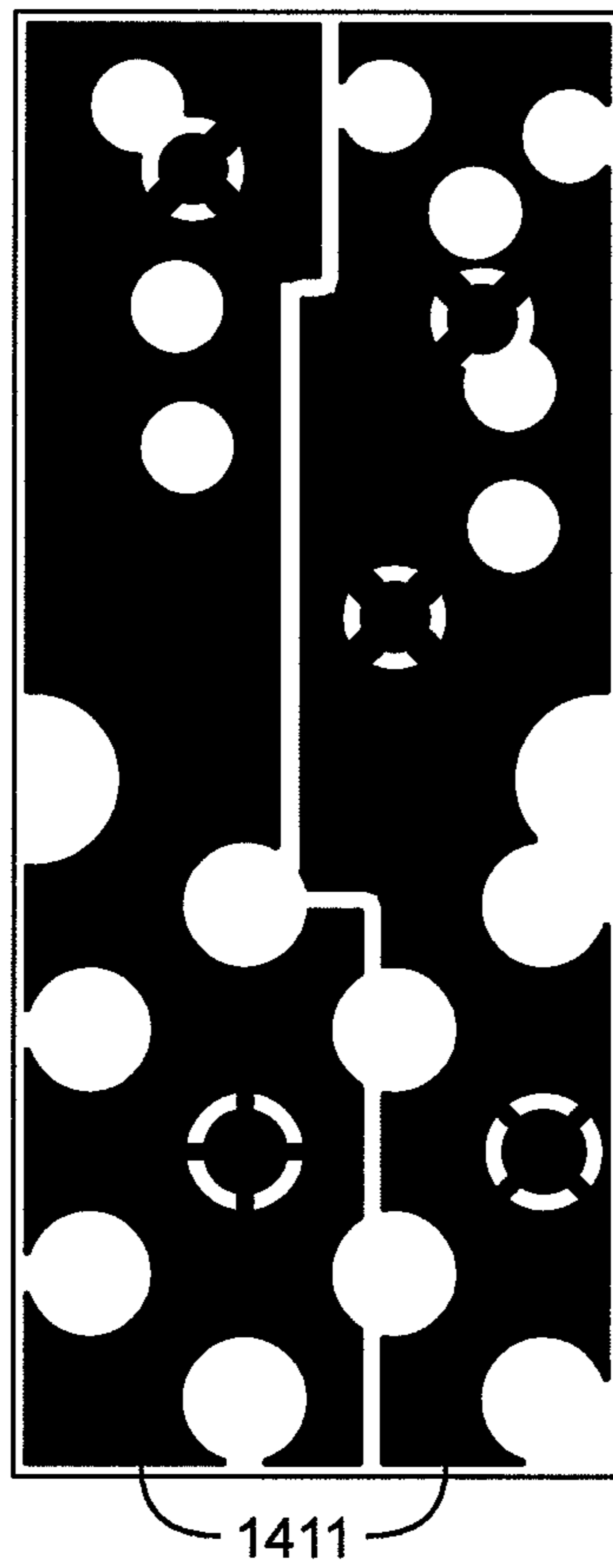


FIG. 18

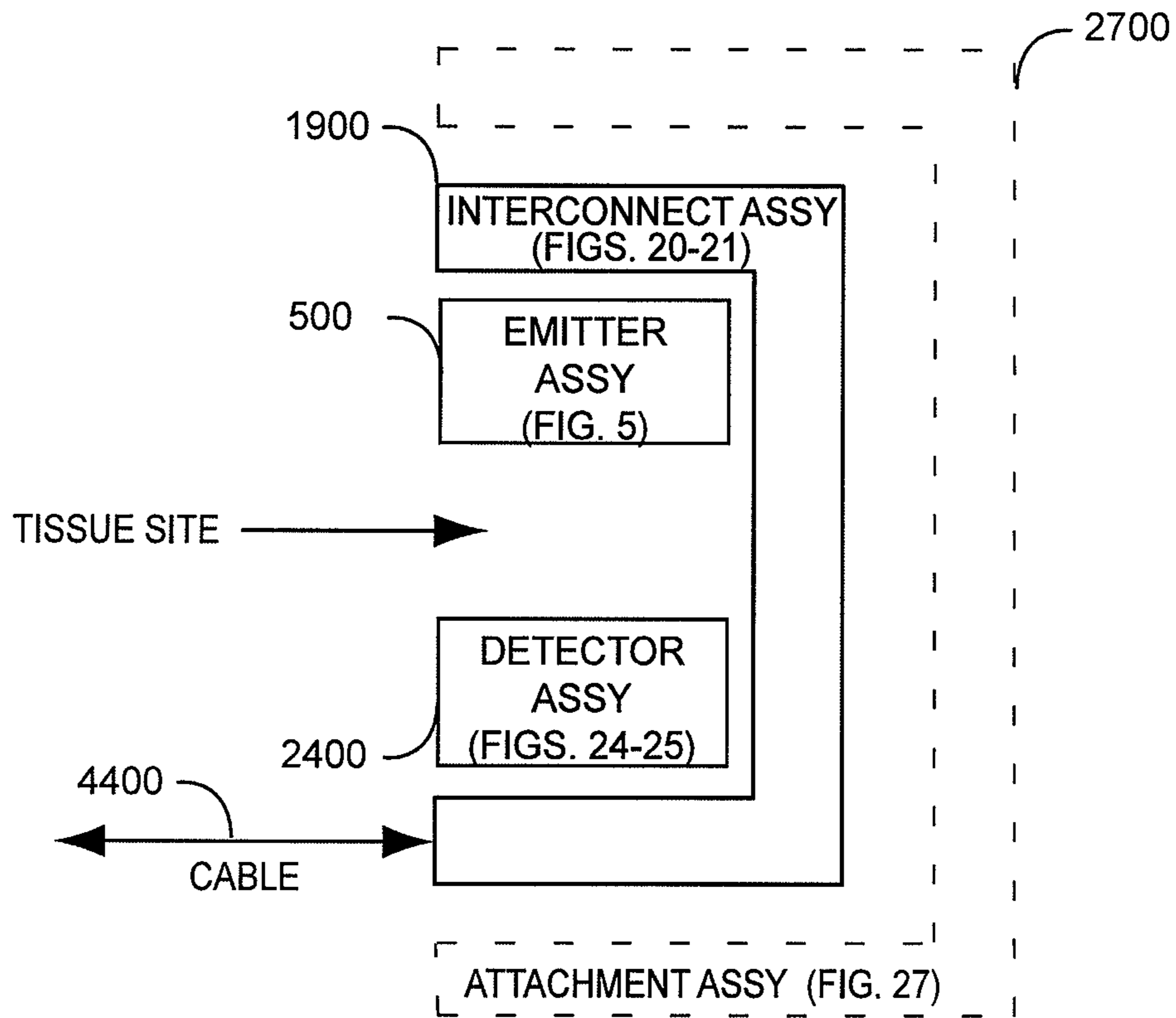


FIG. 19

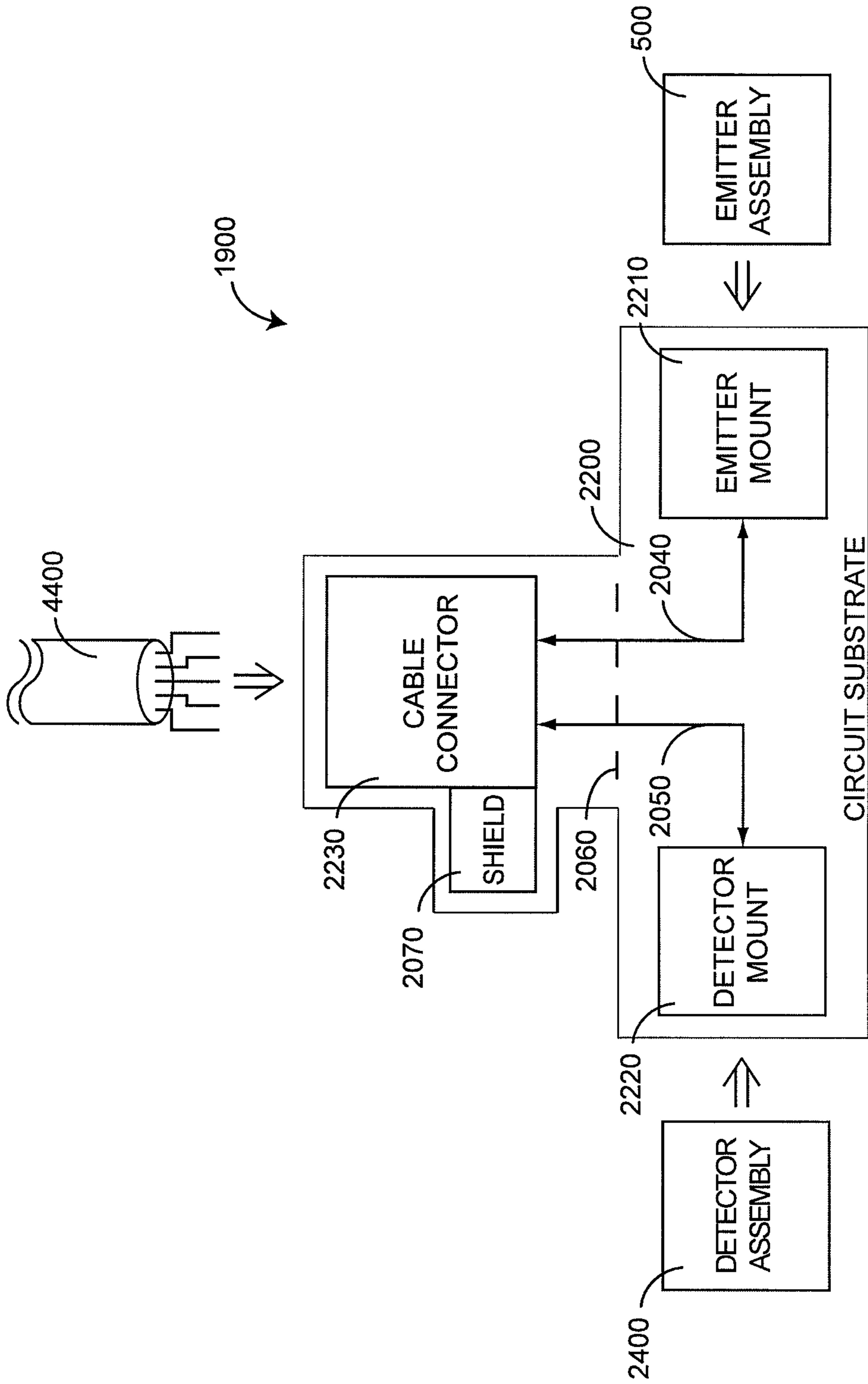


FIG. 20

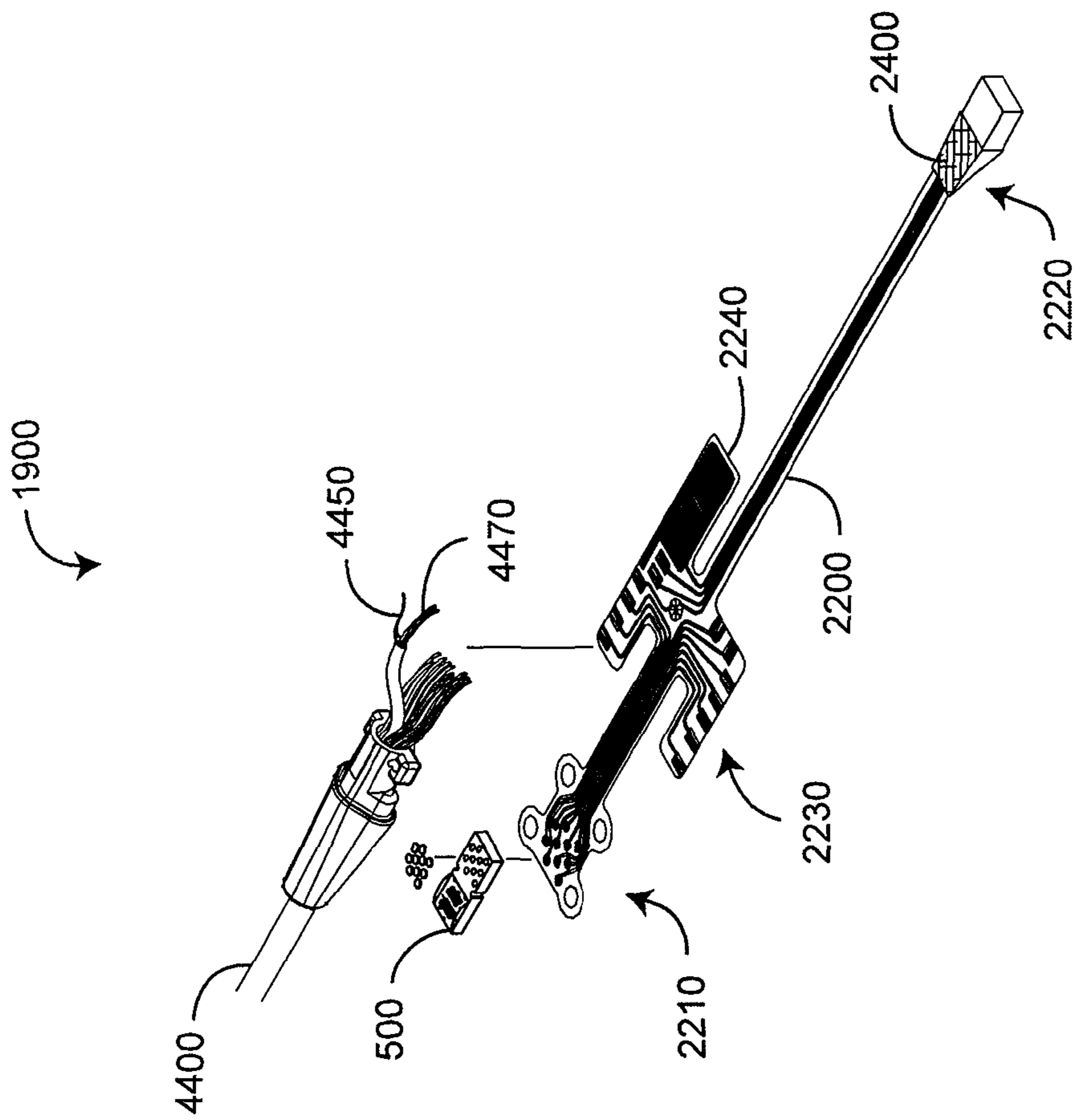


FIG. 21

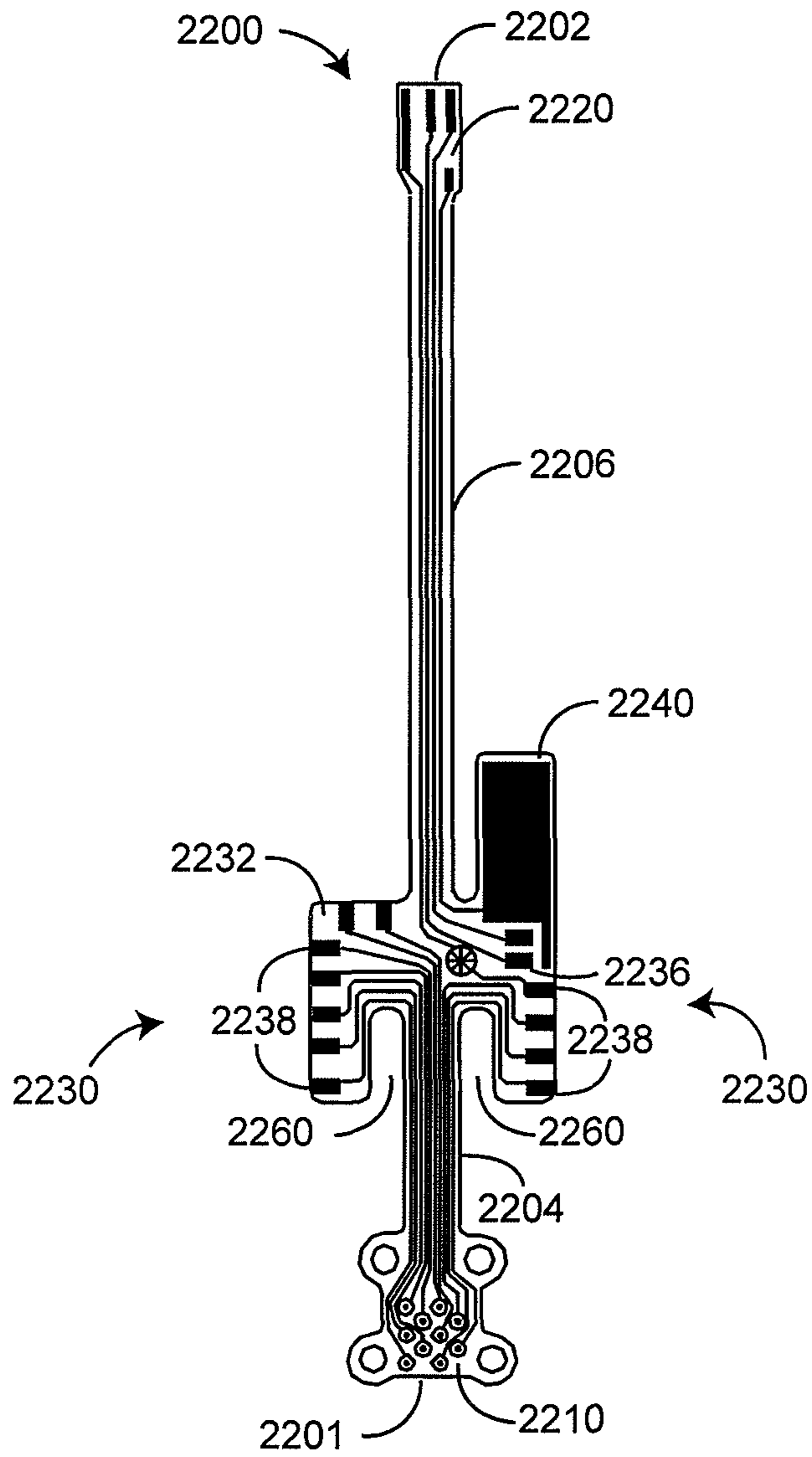


FIG. 22

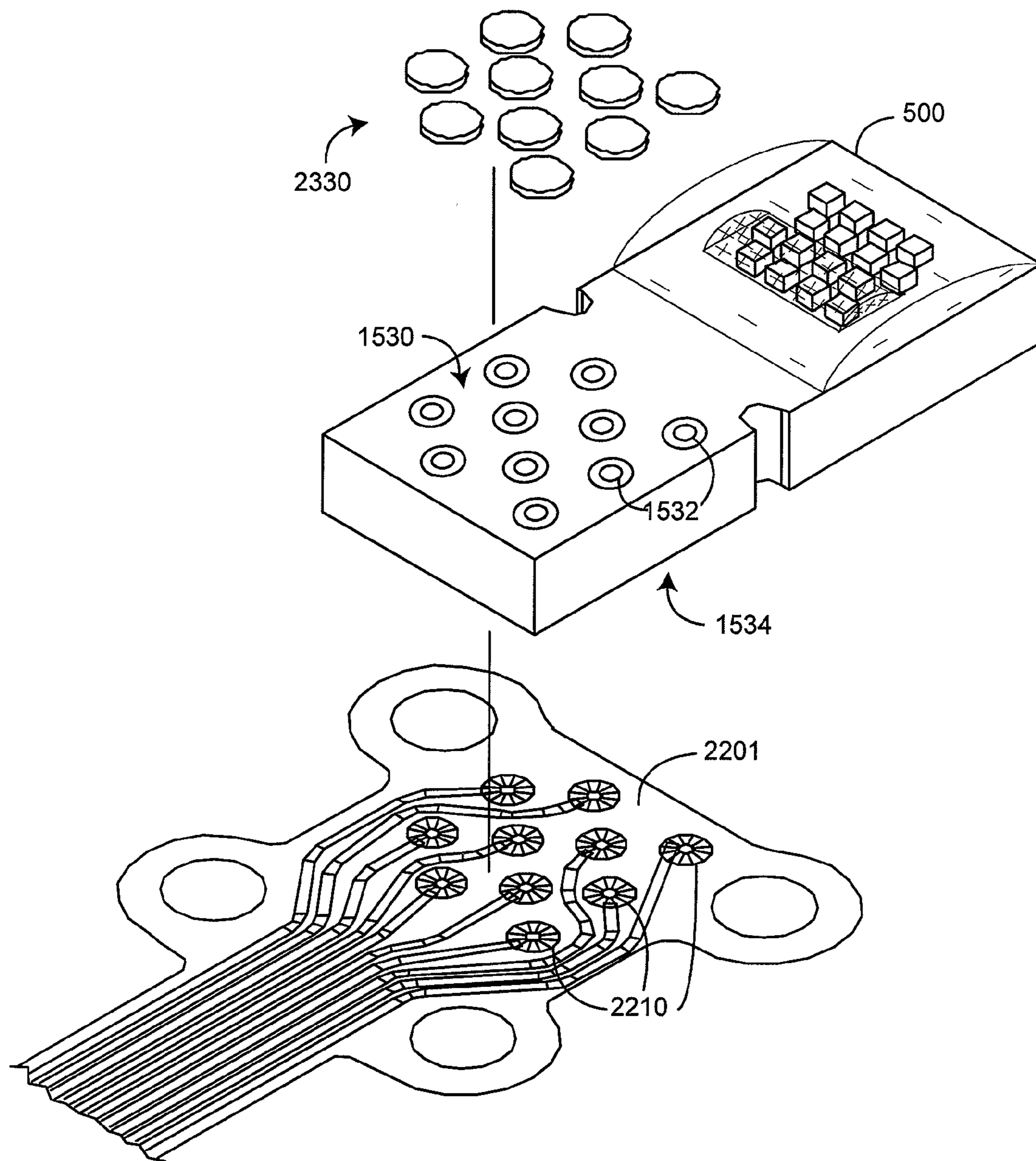


FIG. 23

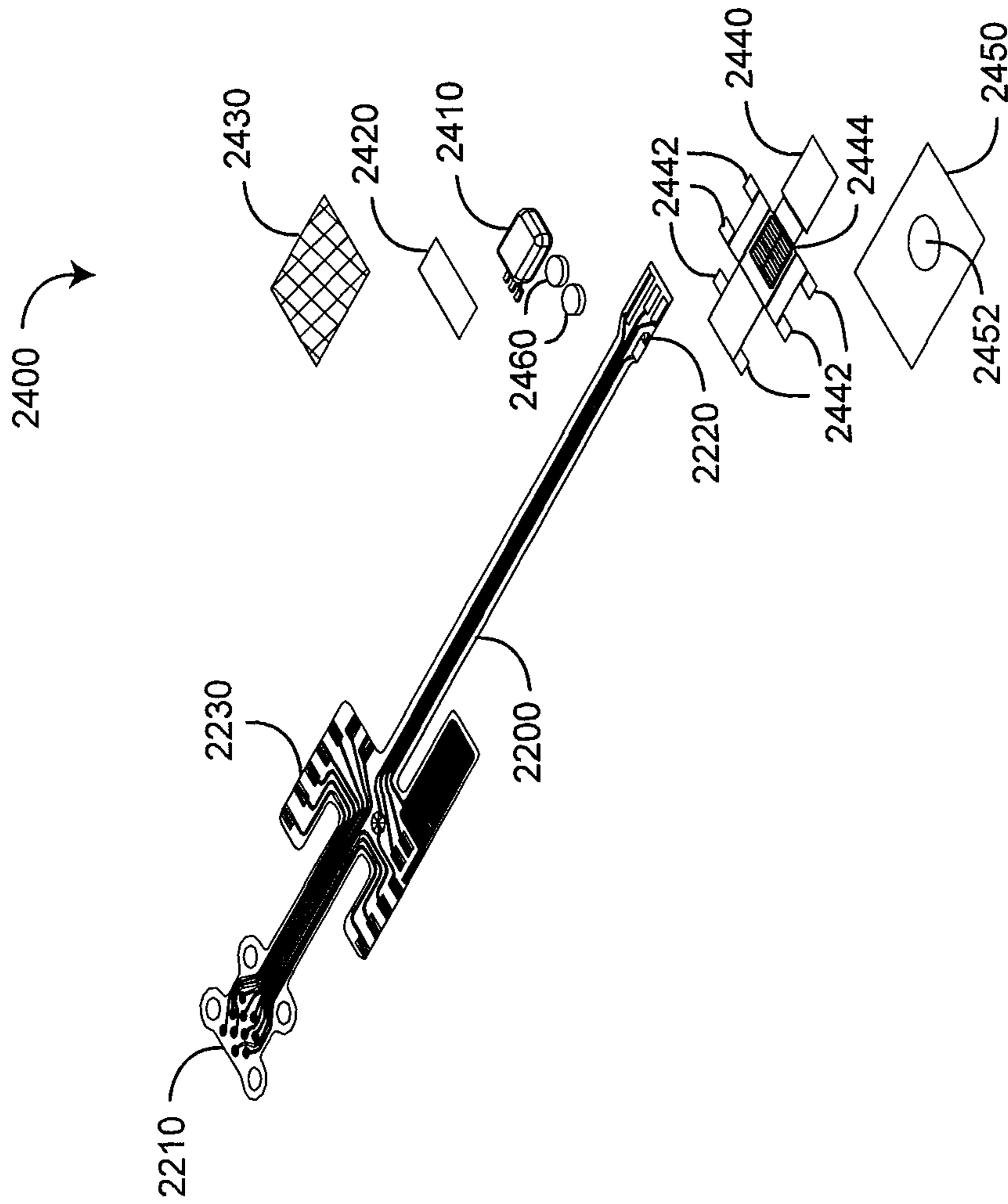


FIG. 24

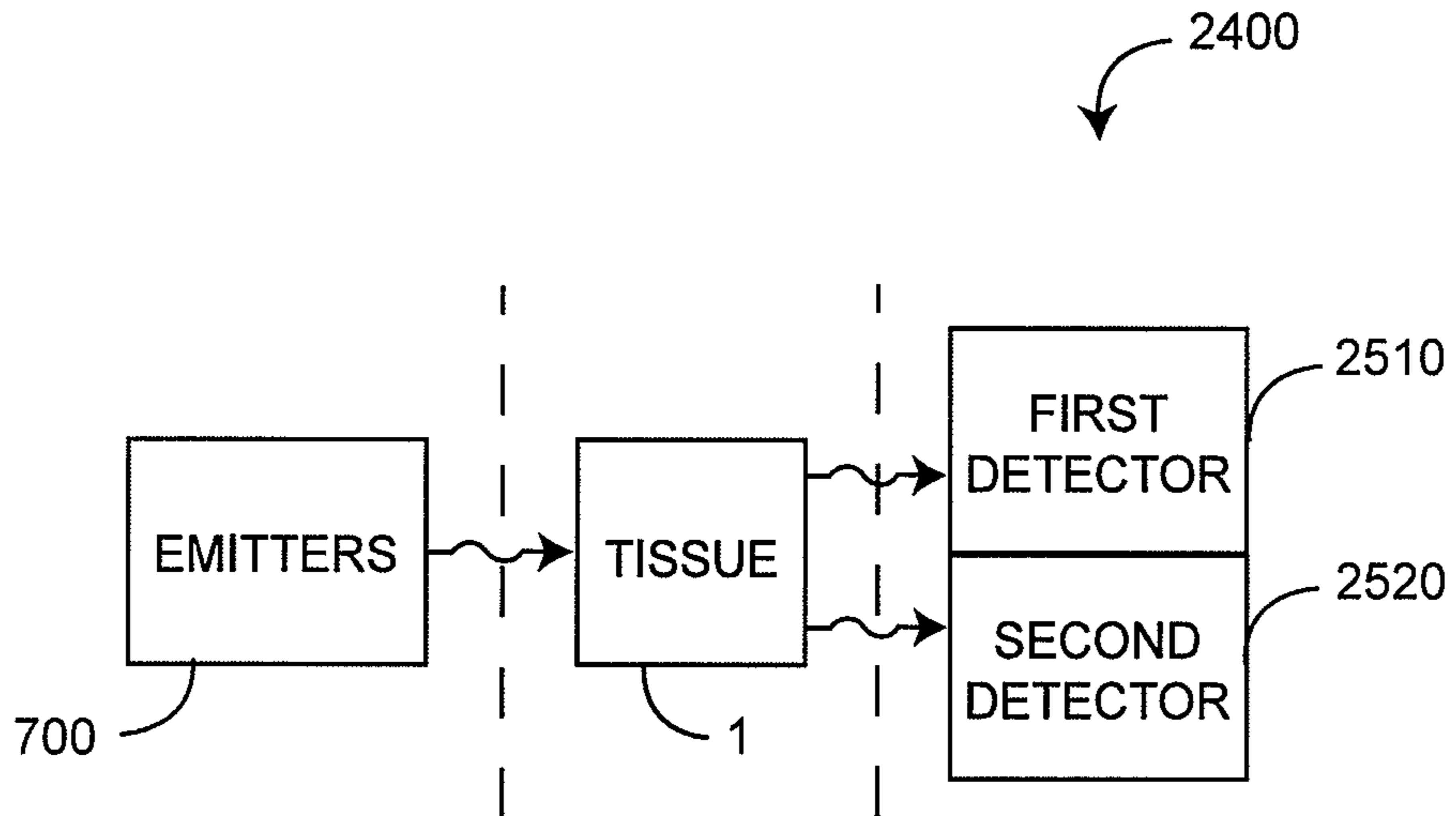


FIG. 25

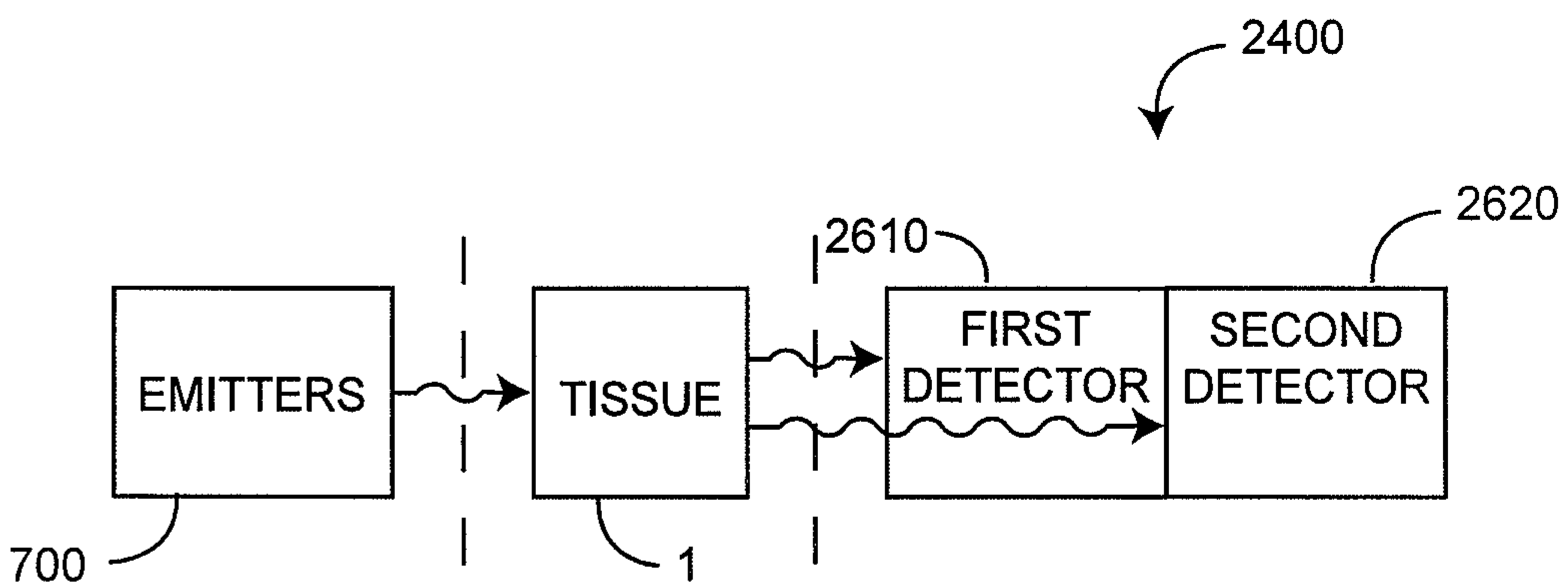


FIG. 26

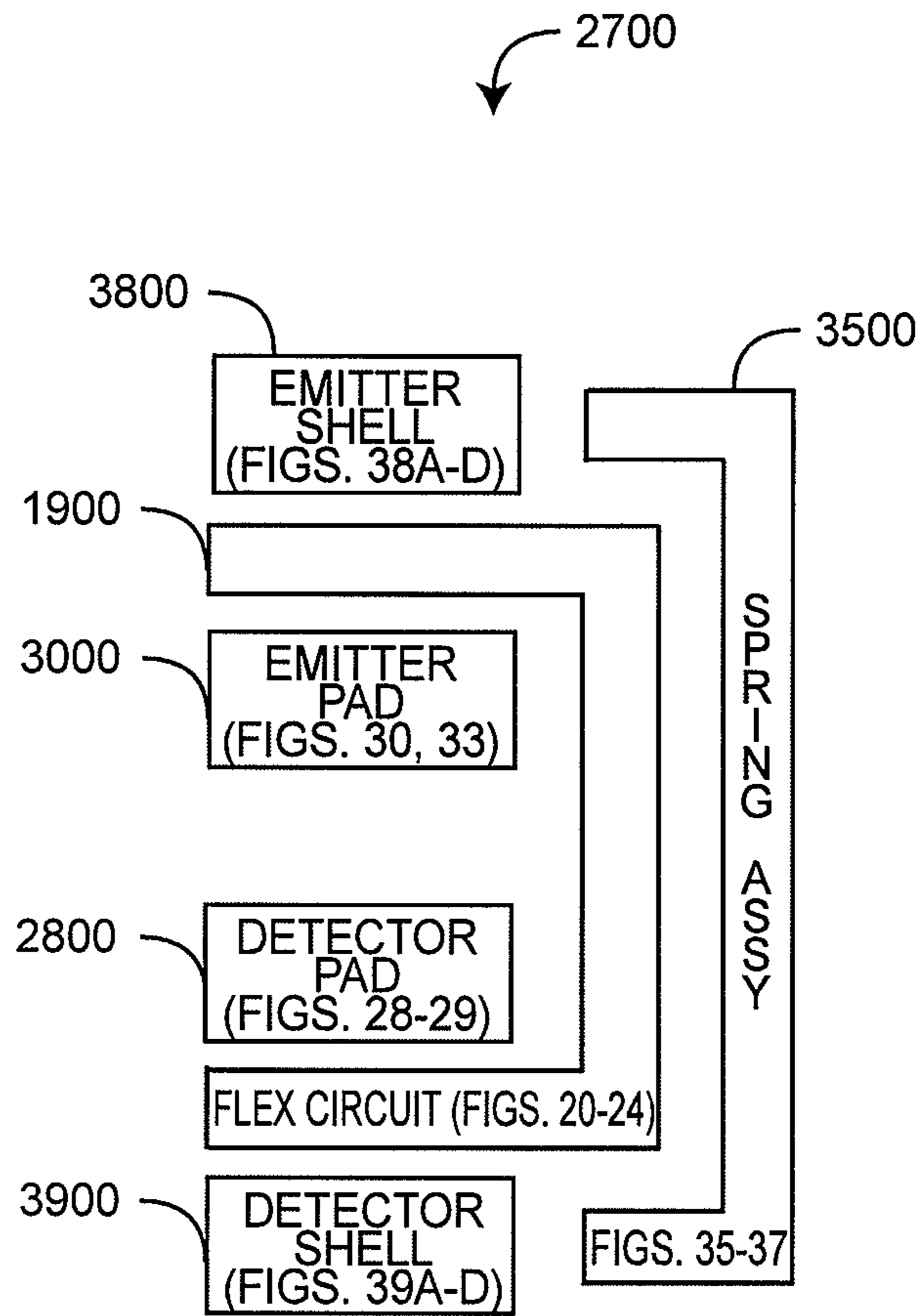


FIG. 27

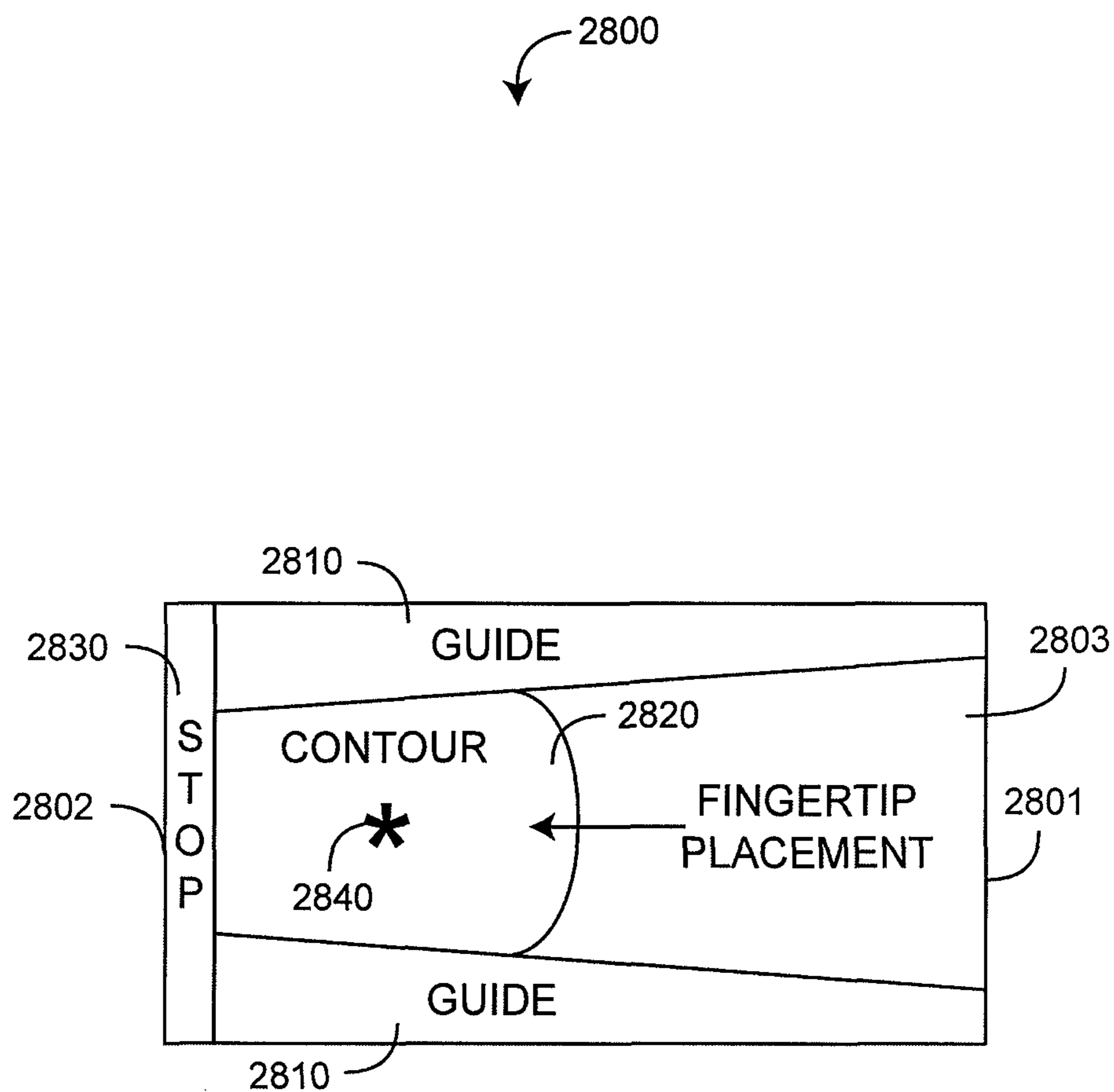


FIG. 28

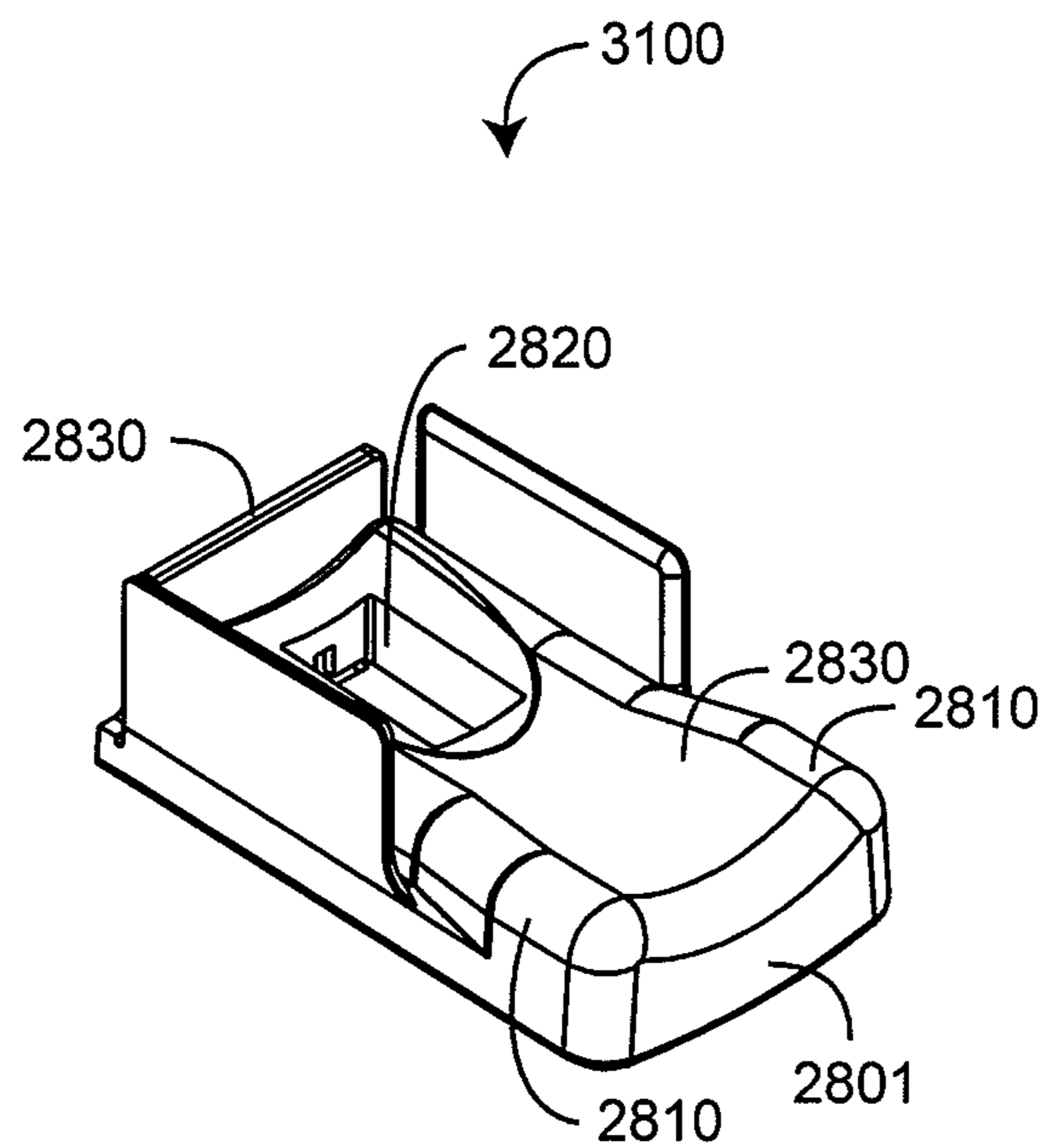


FIG. 29A

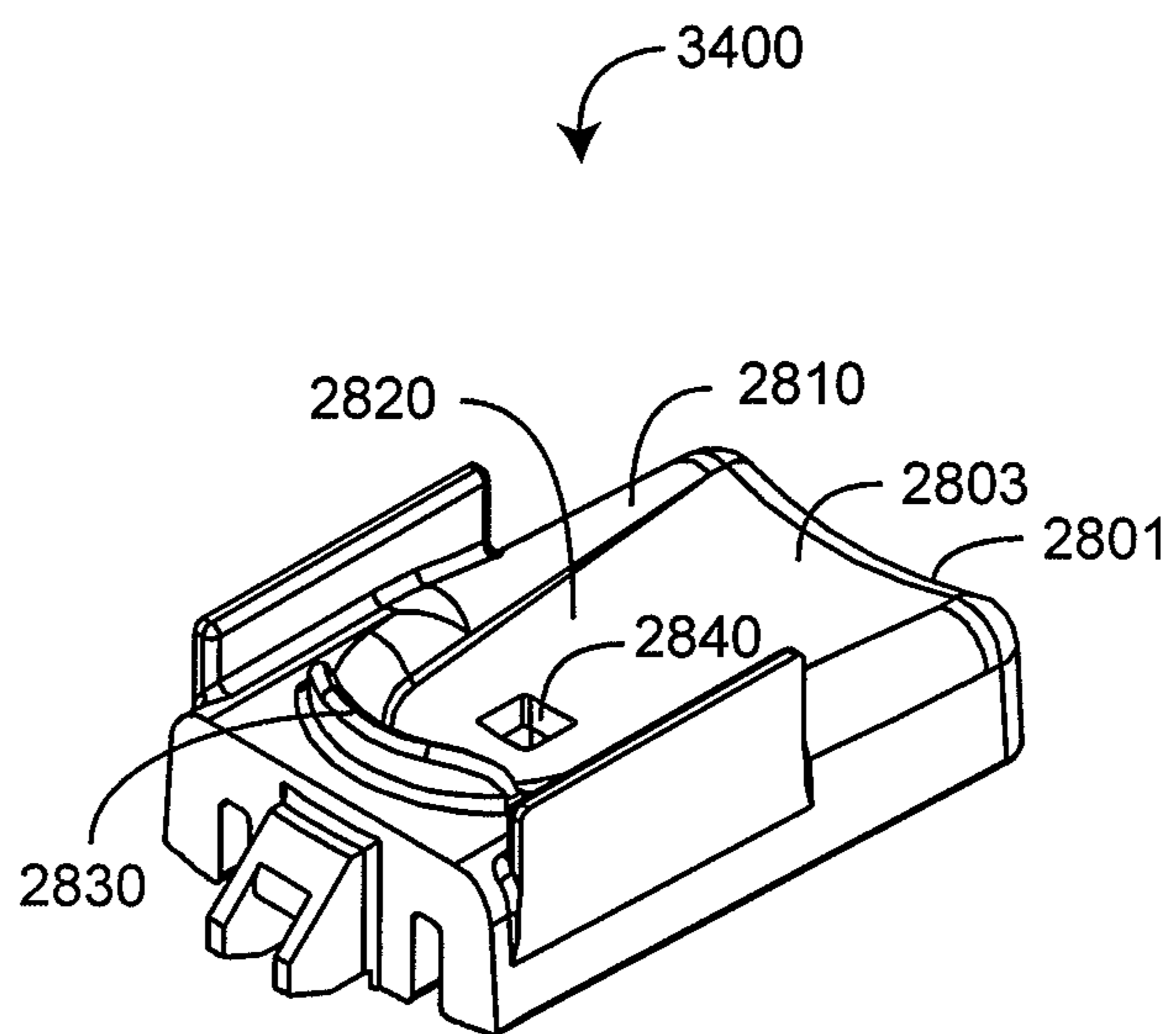


FIG. 29B

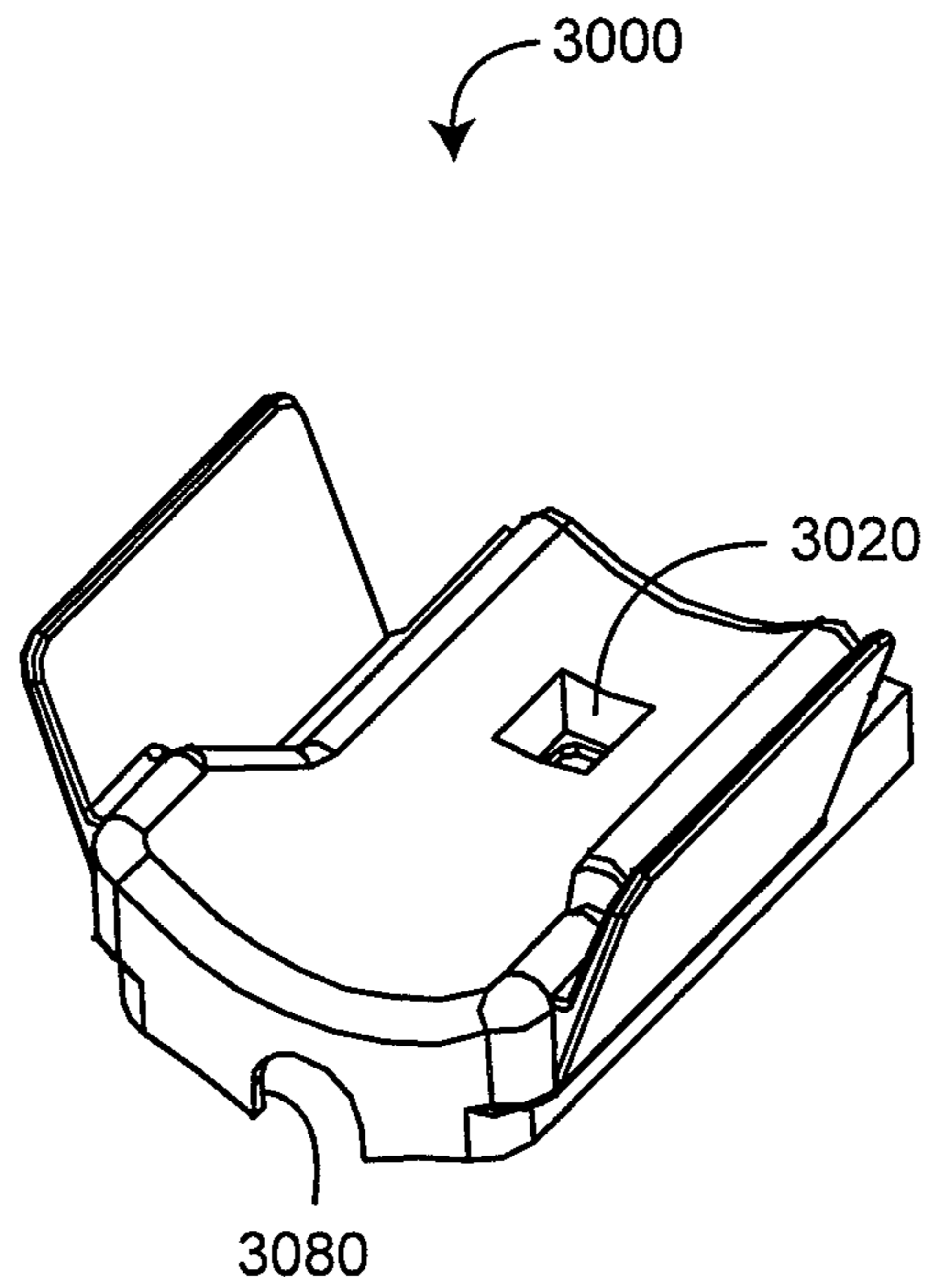


FIG. 30A

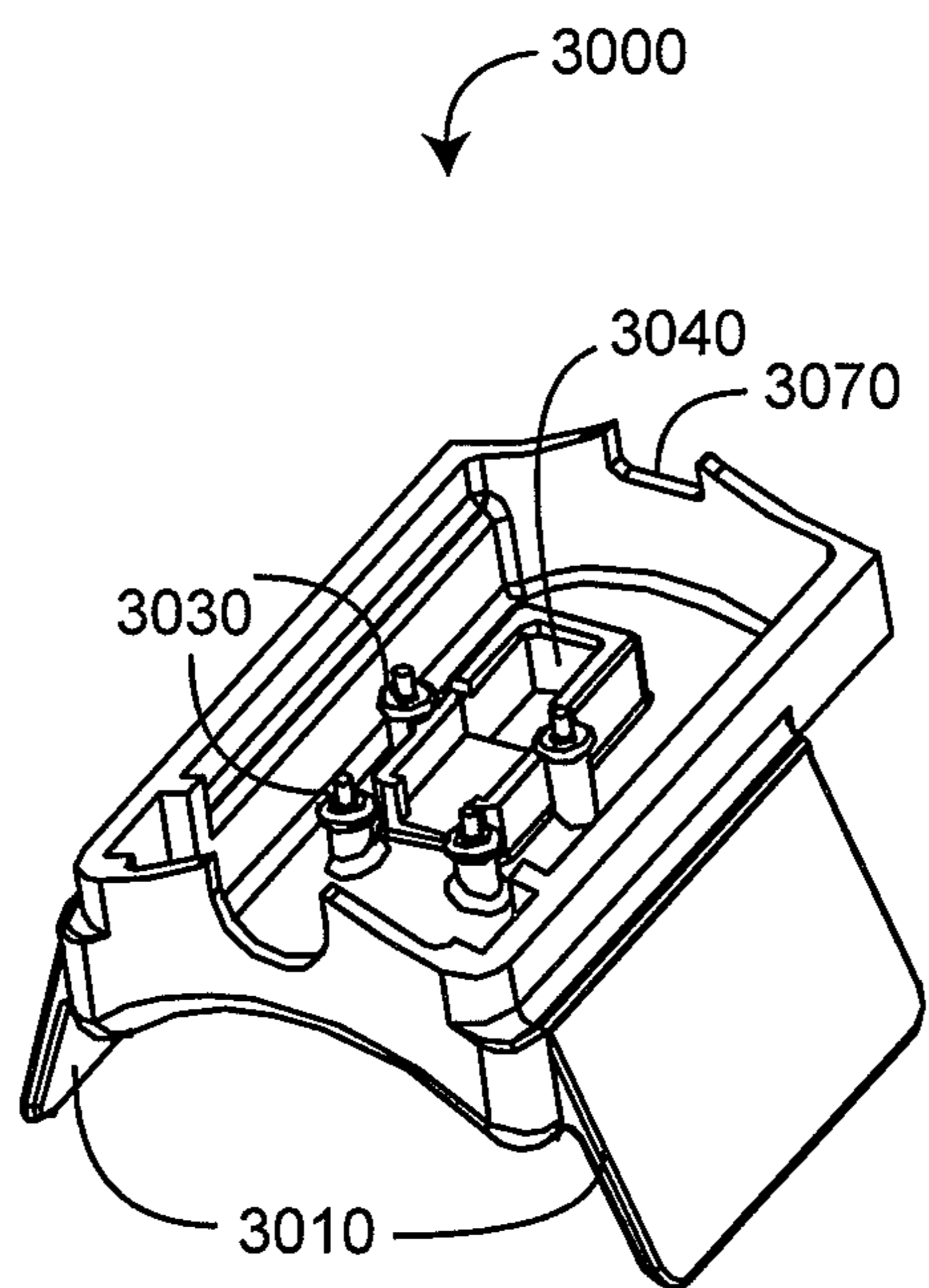


FIG. 30B

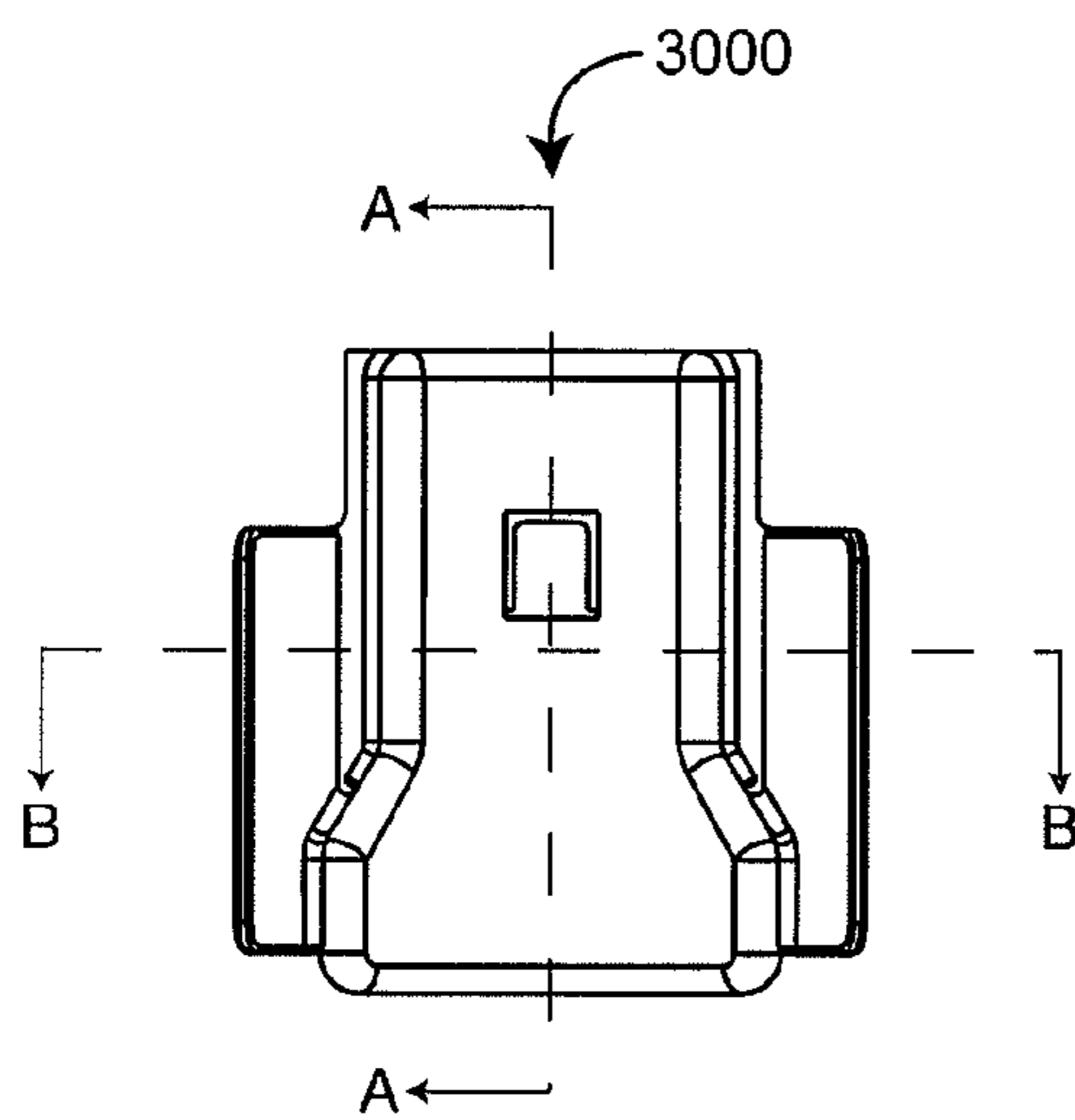
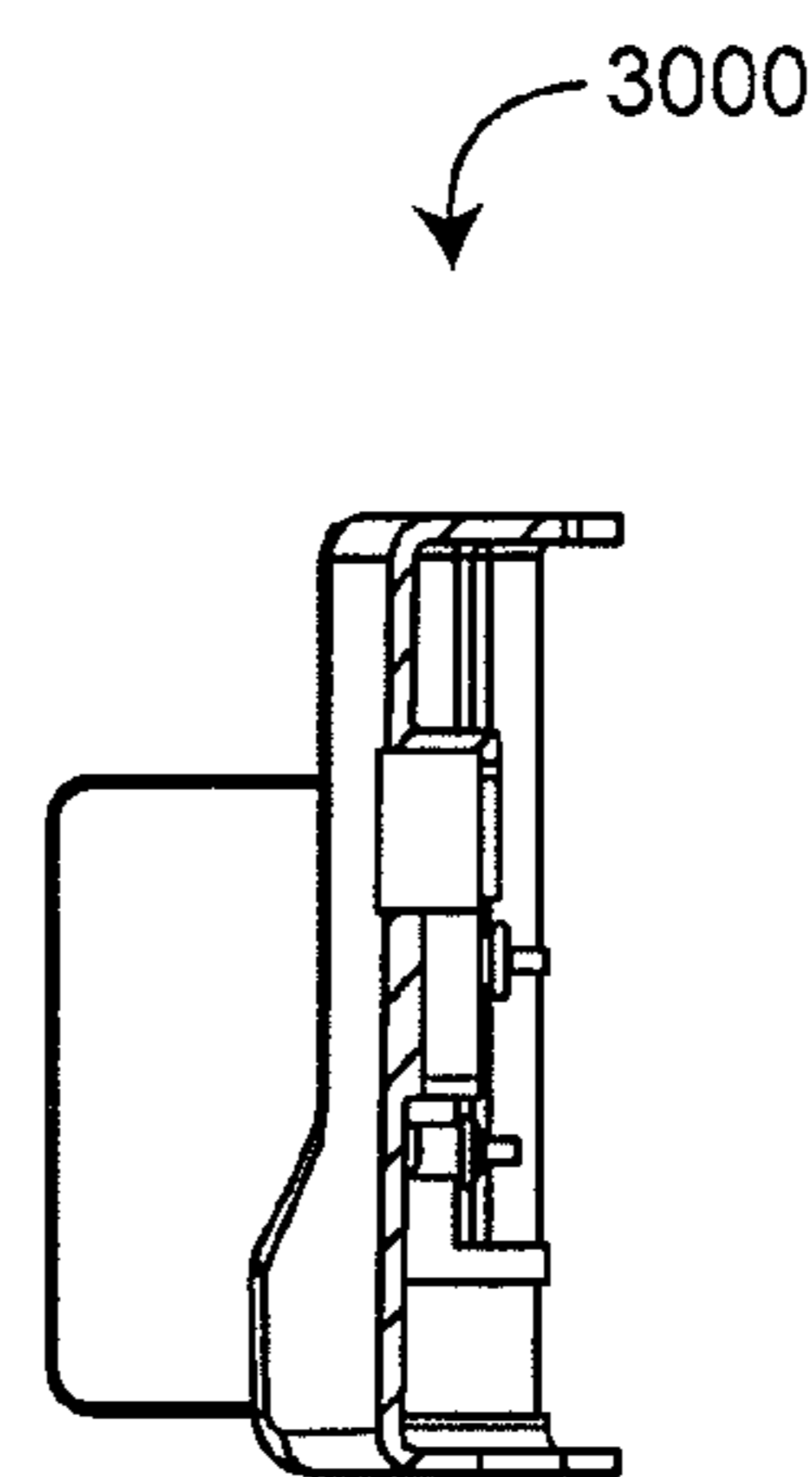


FIG. 30C



SECTION A-A

FIG. 30F

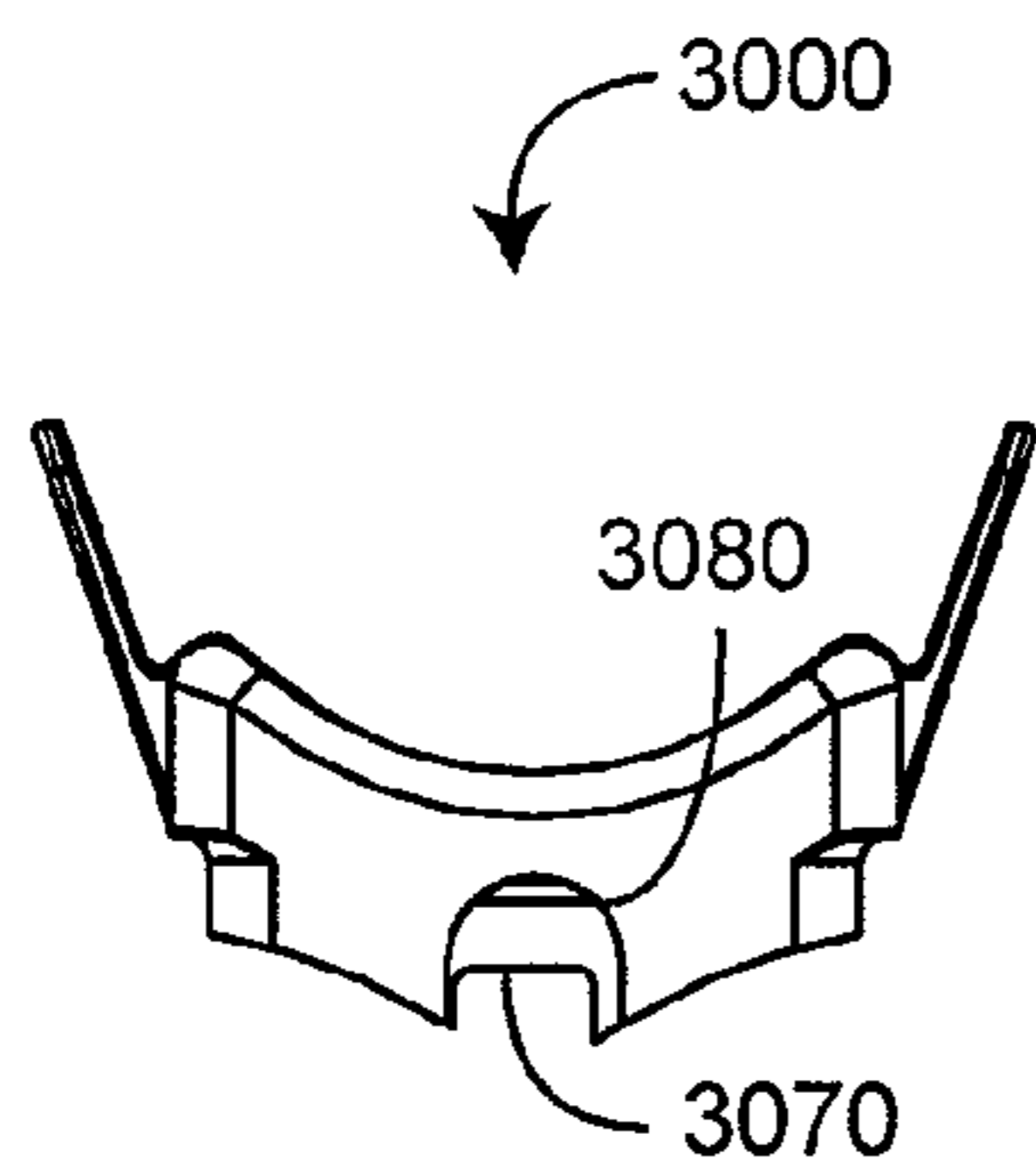


FIG. 30D

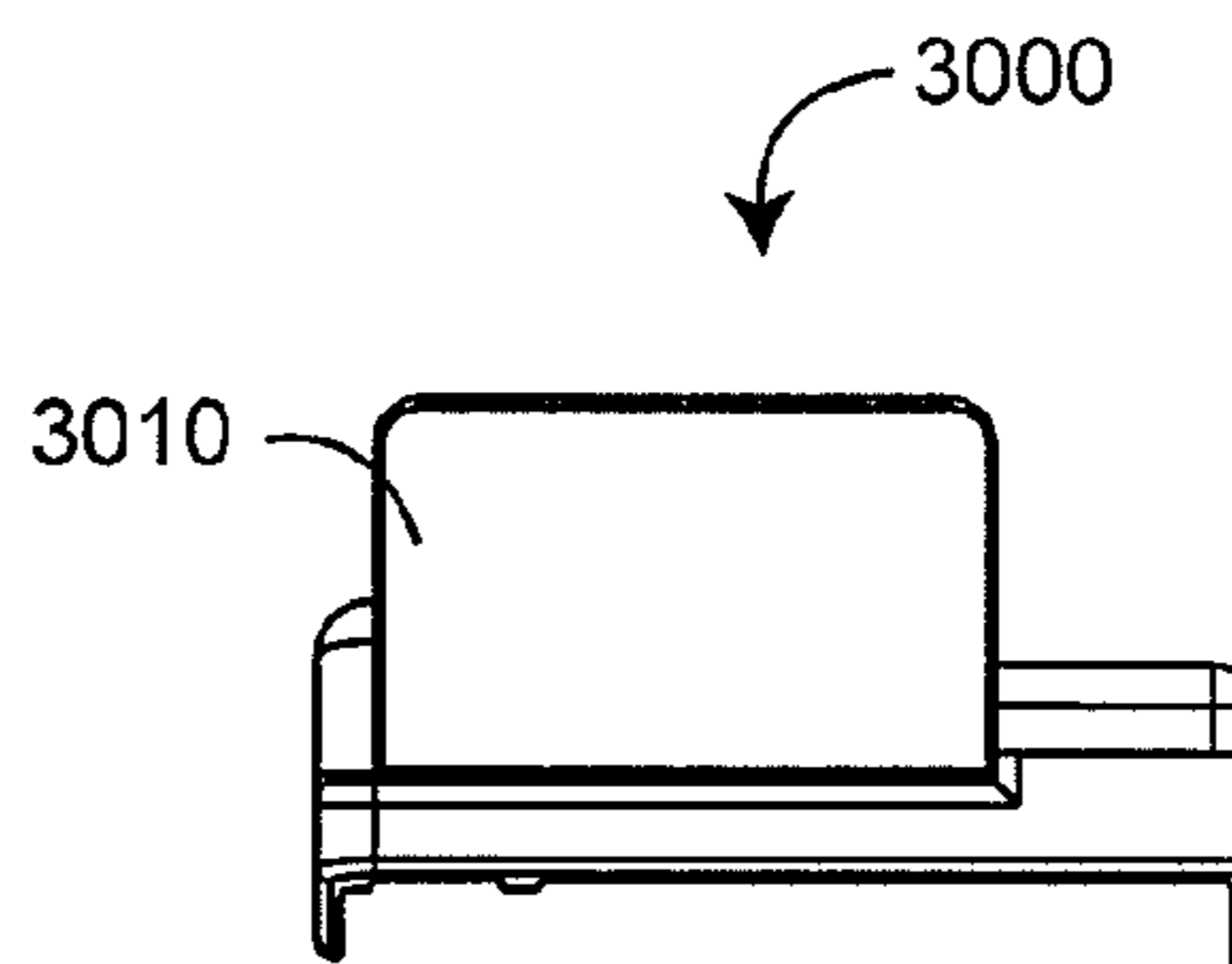


FIG. 30G

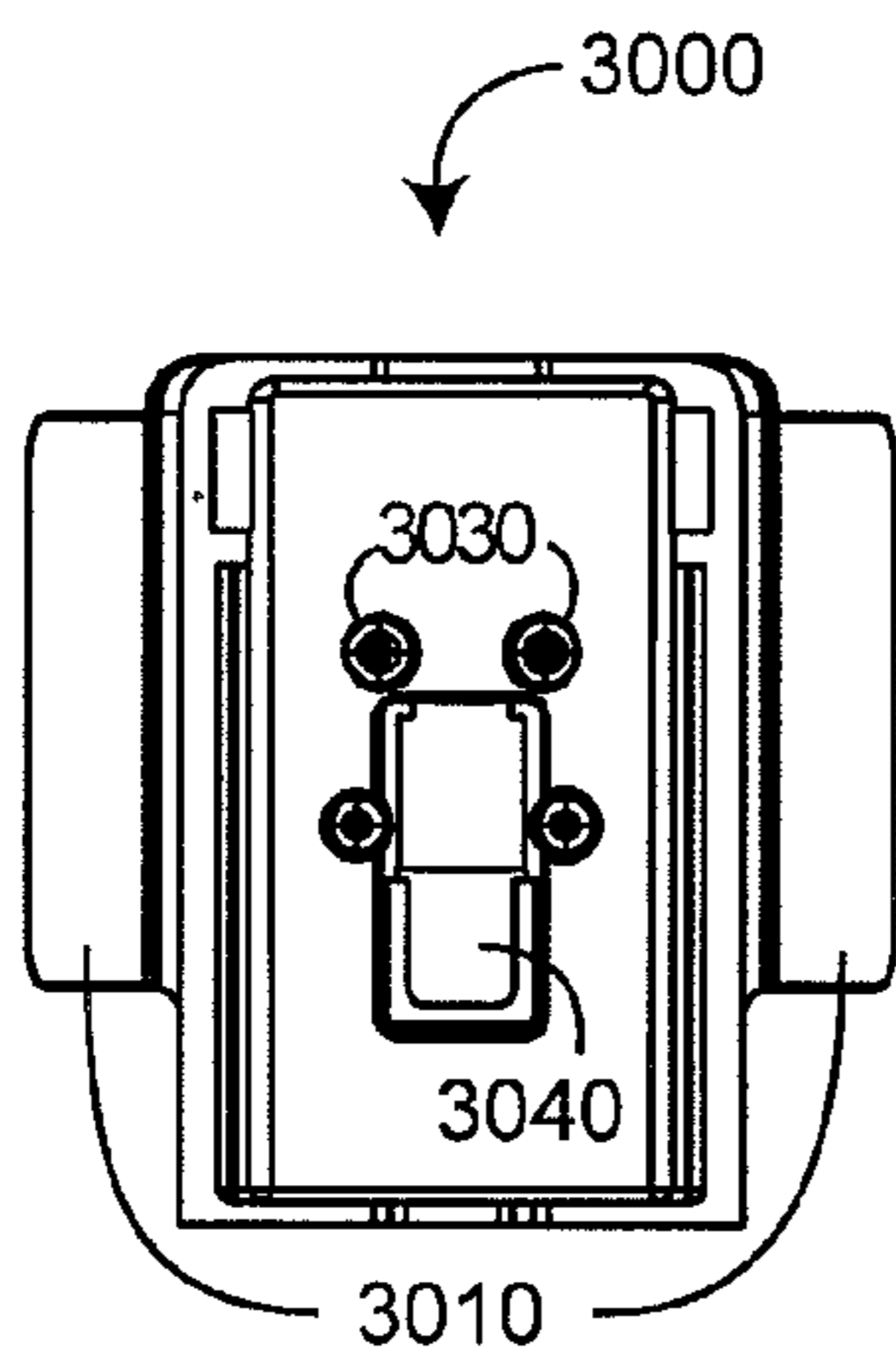
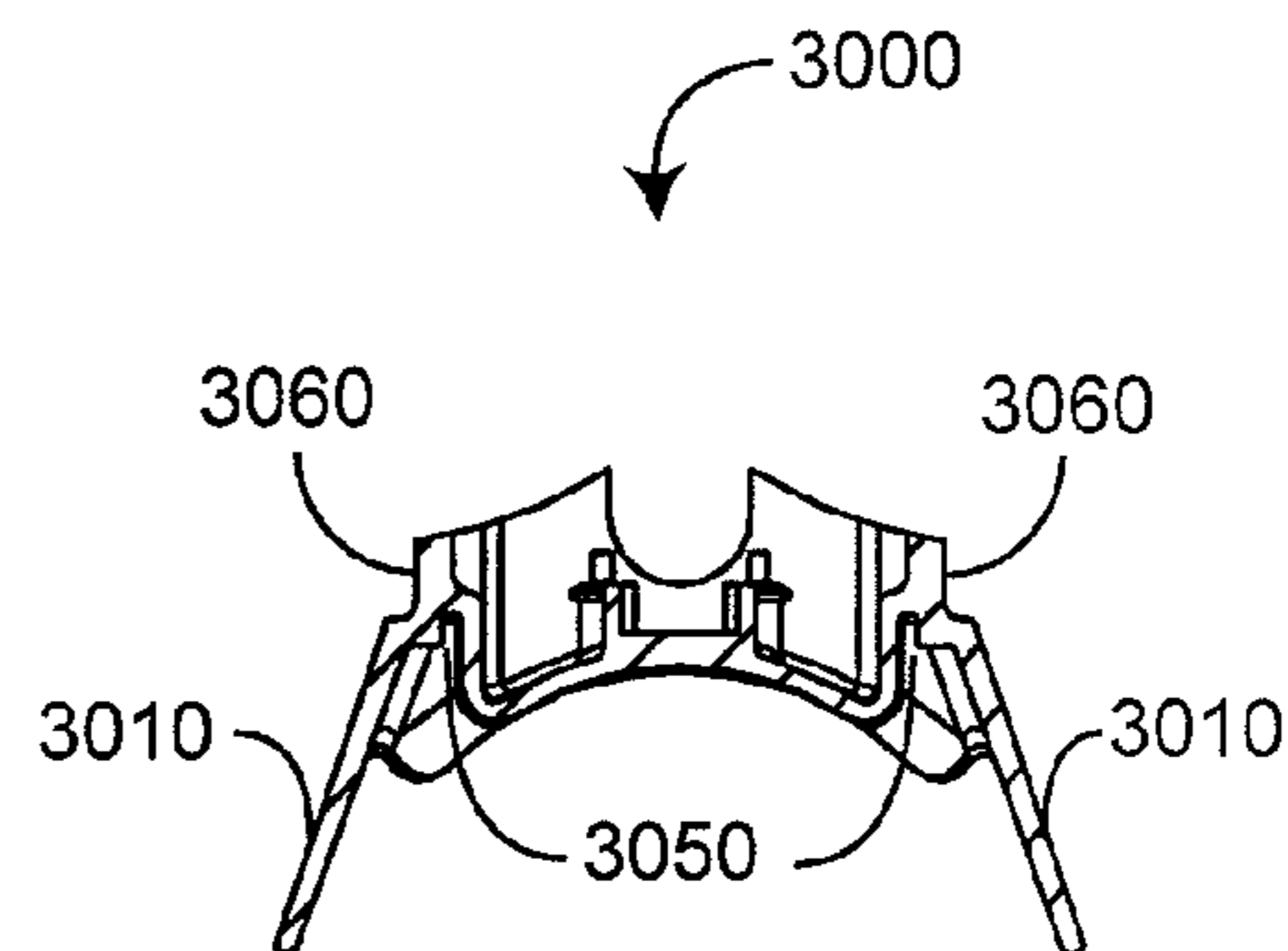


FIG. 30E



SECTION B-B

FIG. 30H

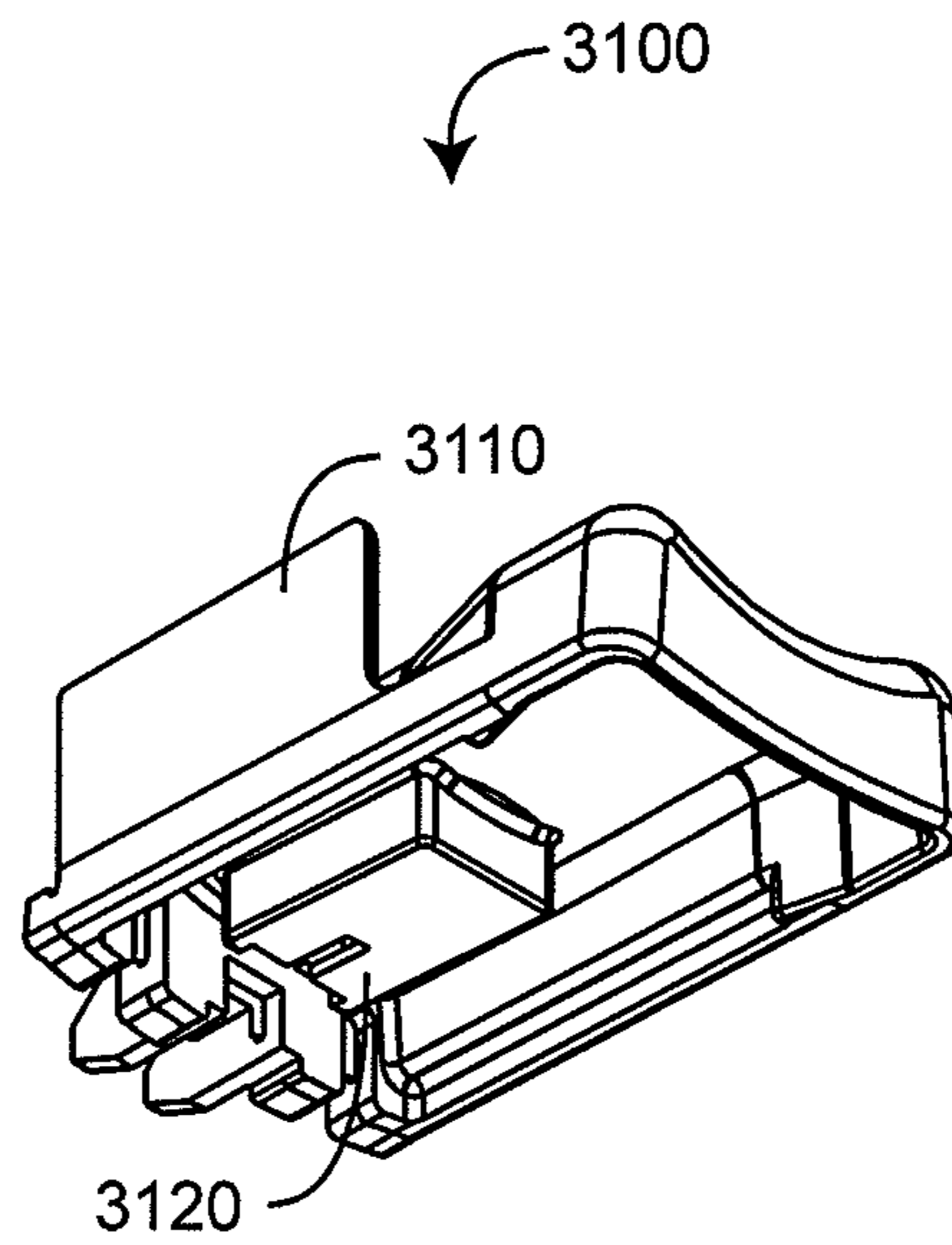


FIG. 31A

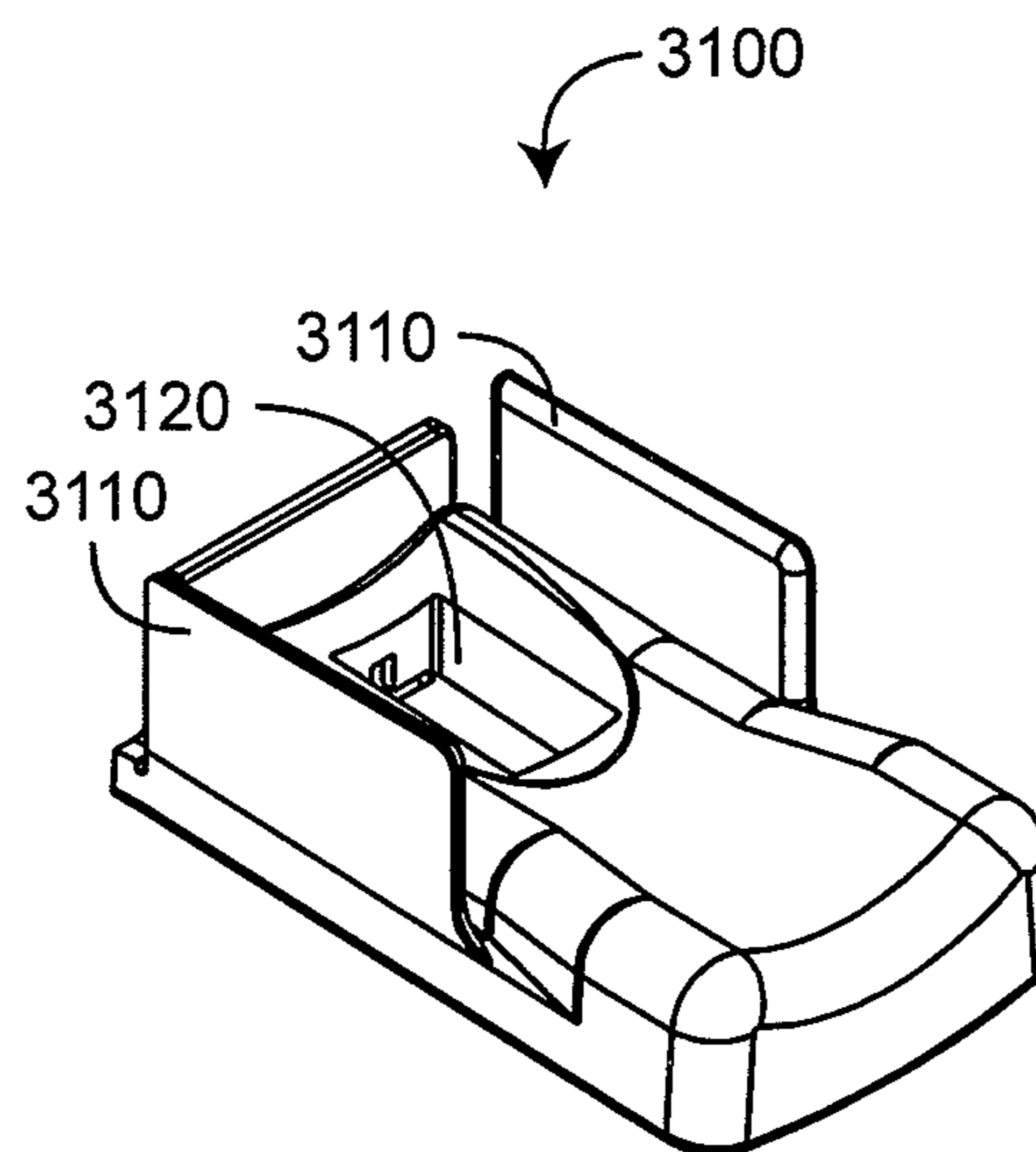


FIG. 31B

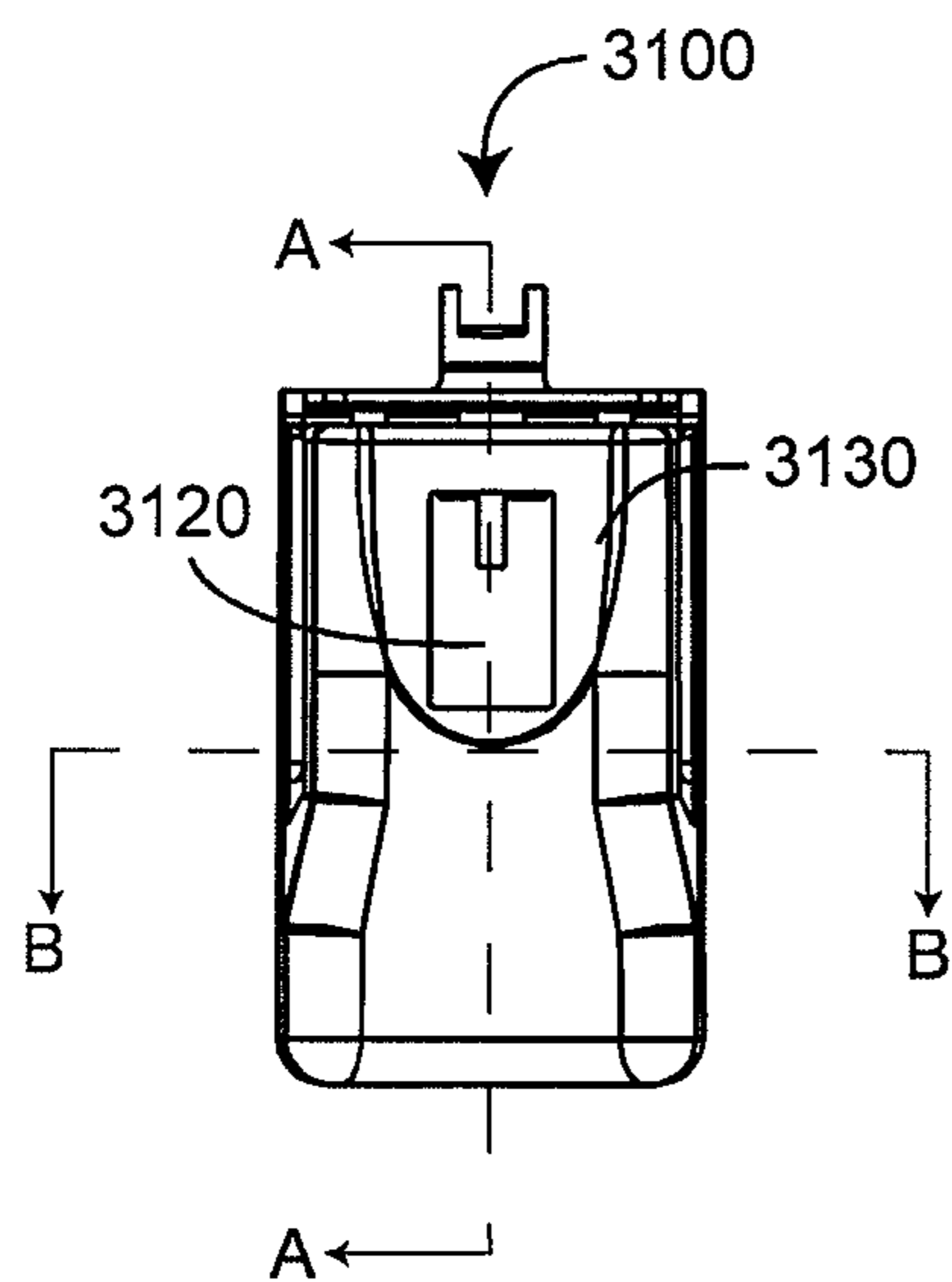
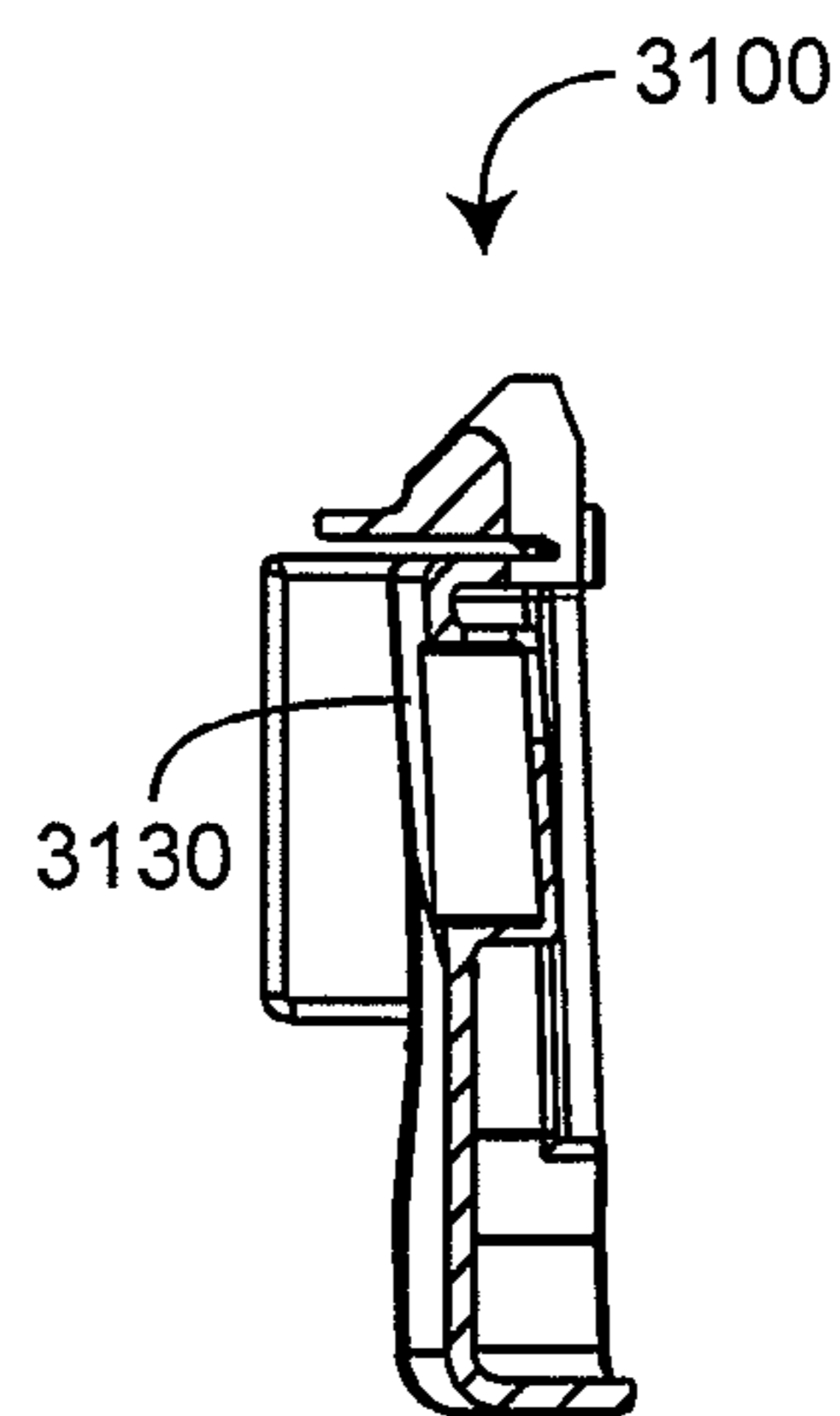


FIG. 31C



SECTION A-A
FIG. 31F

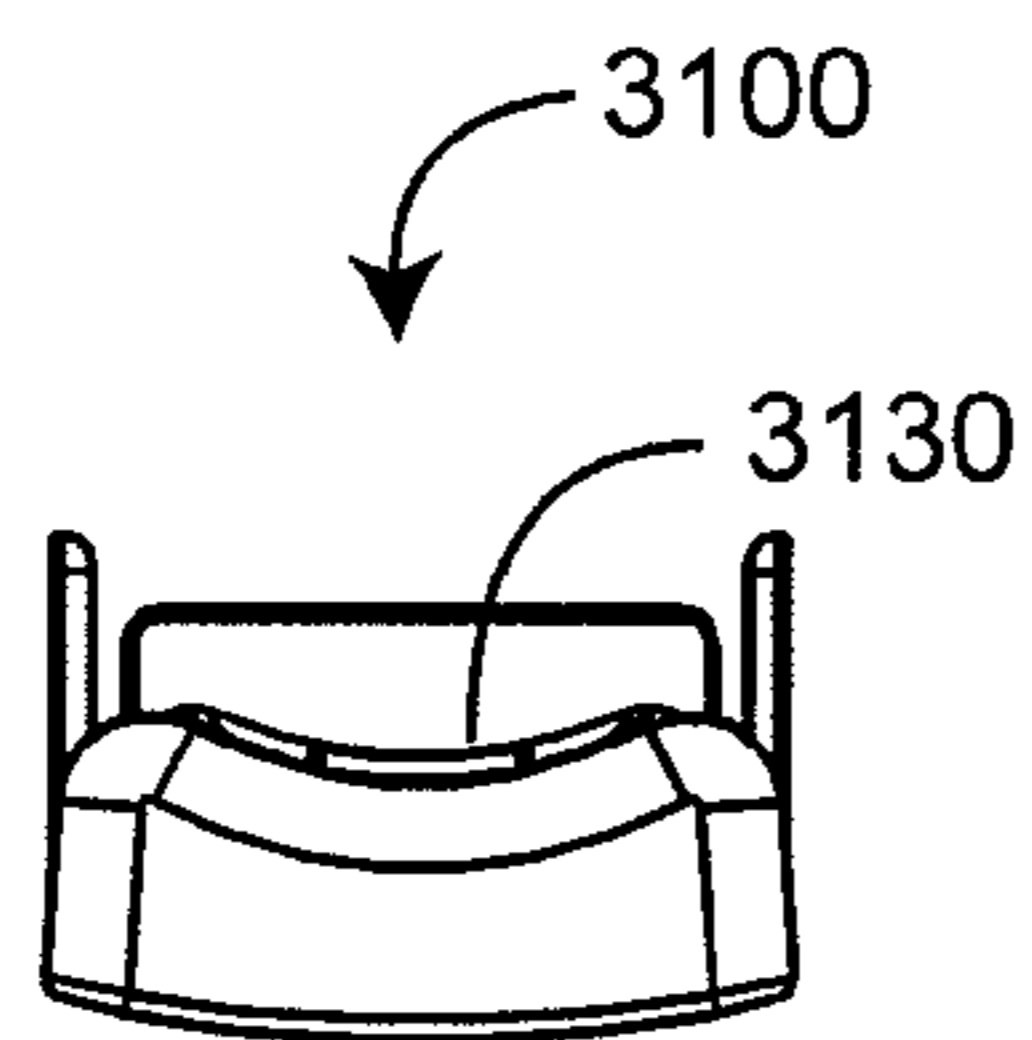


FIG. 31D

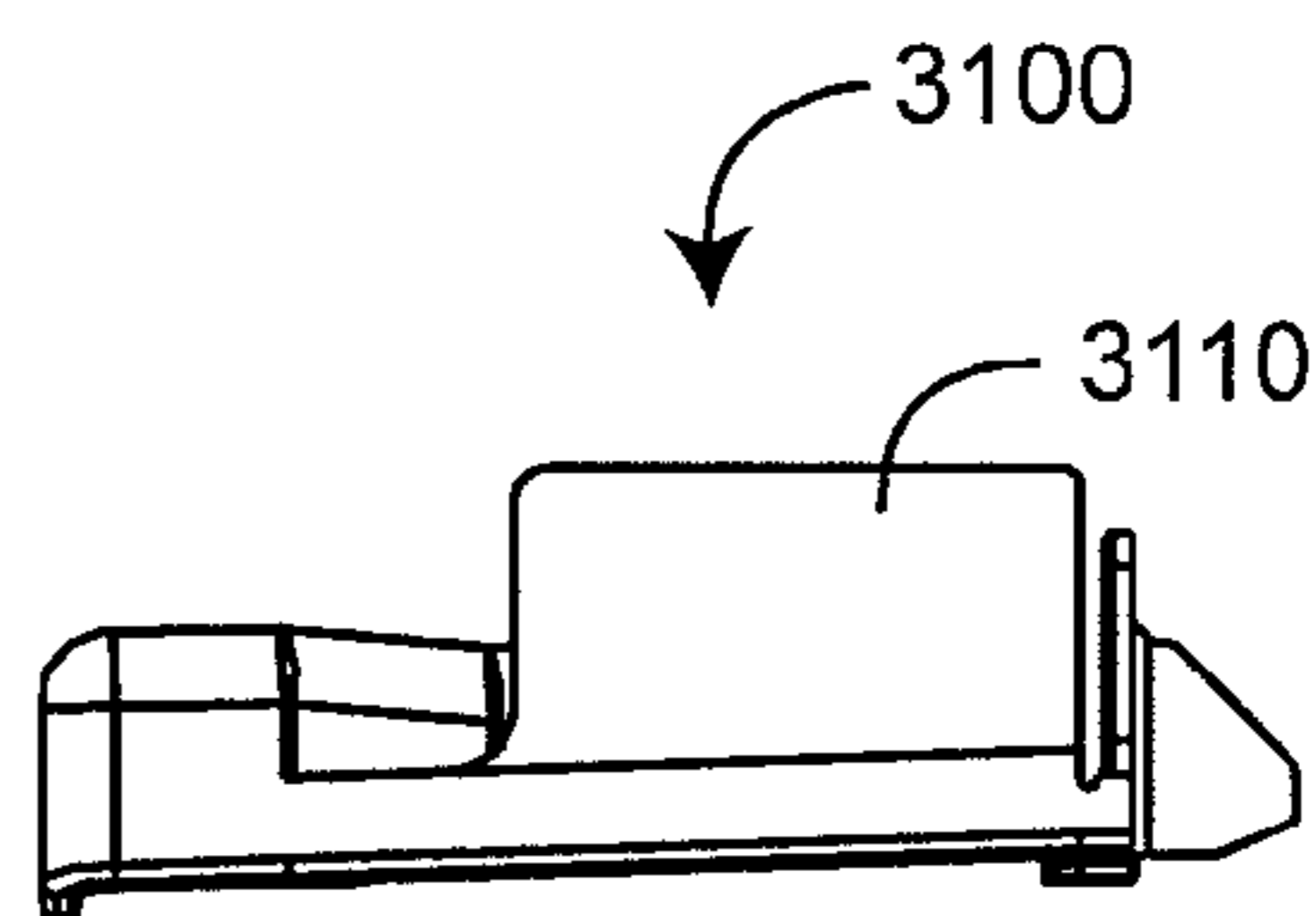


FIG. 31G

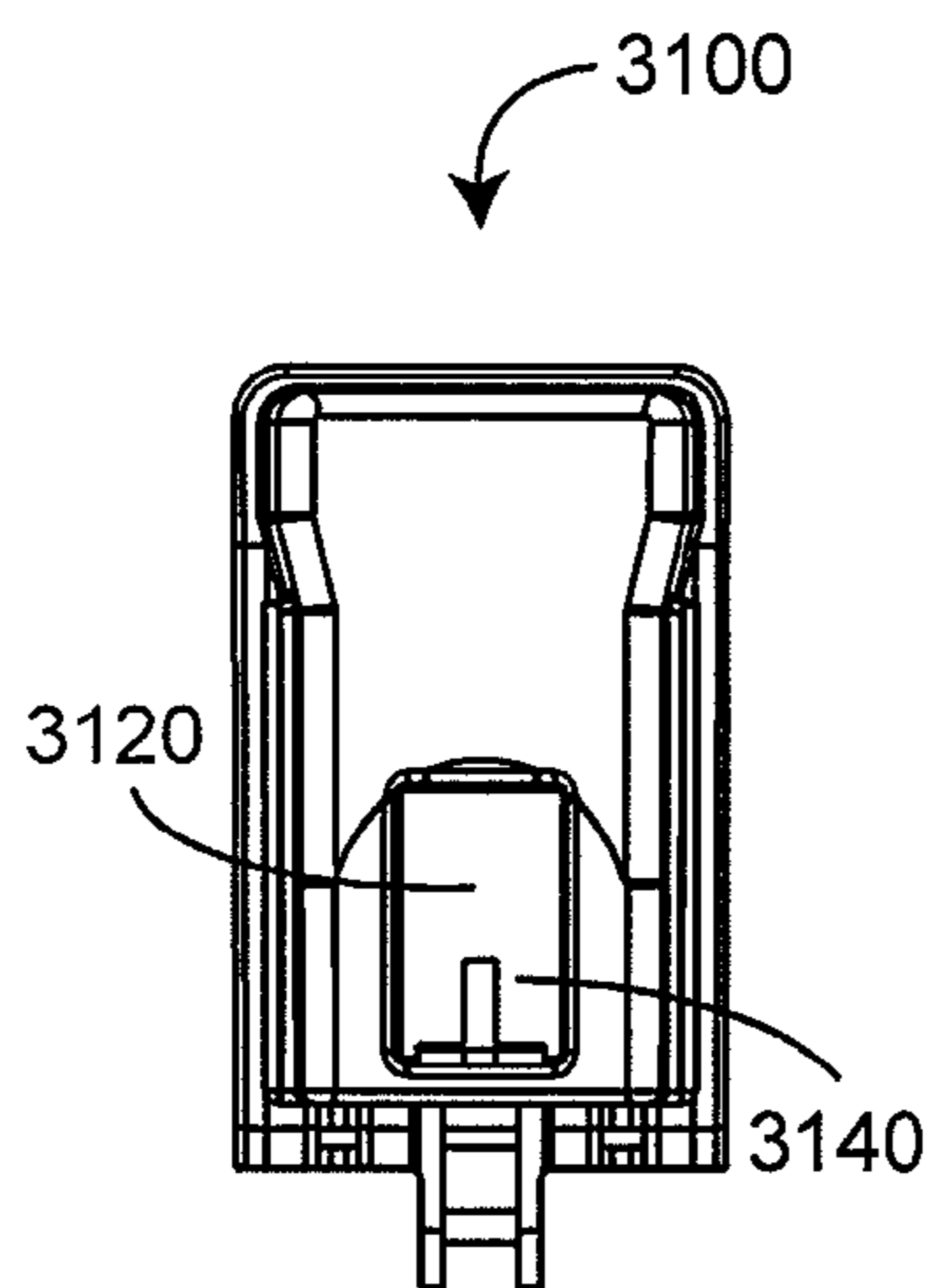
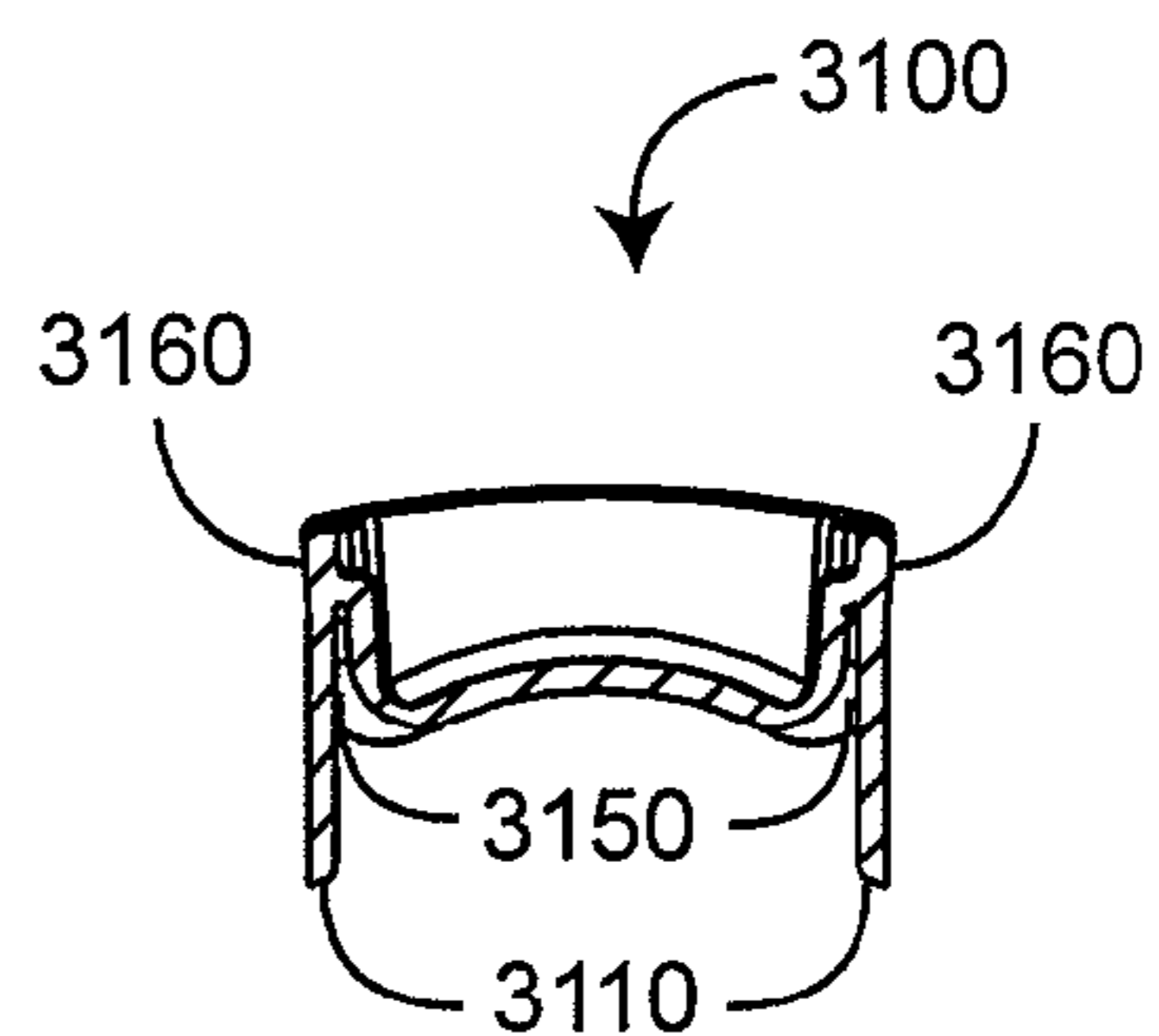


FIG. 31E



SECTION B-B
FIG. 31H

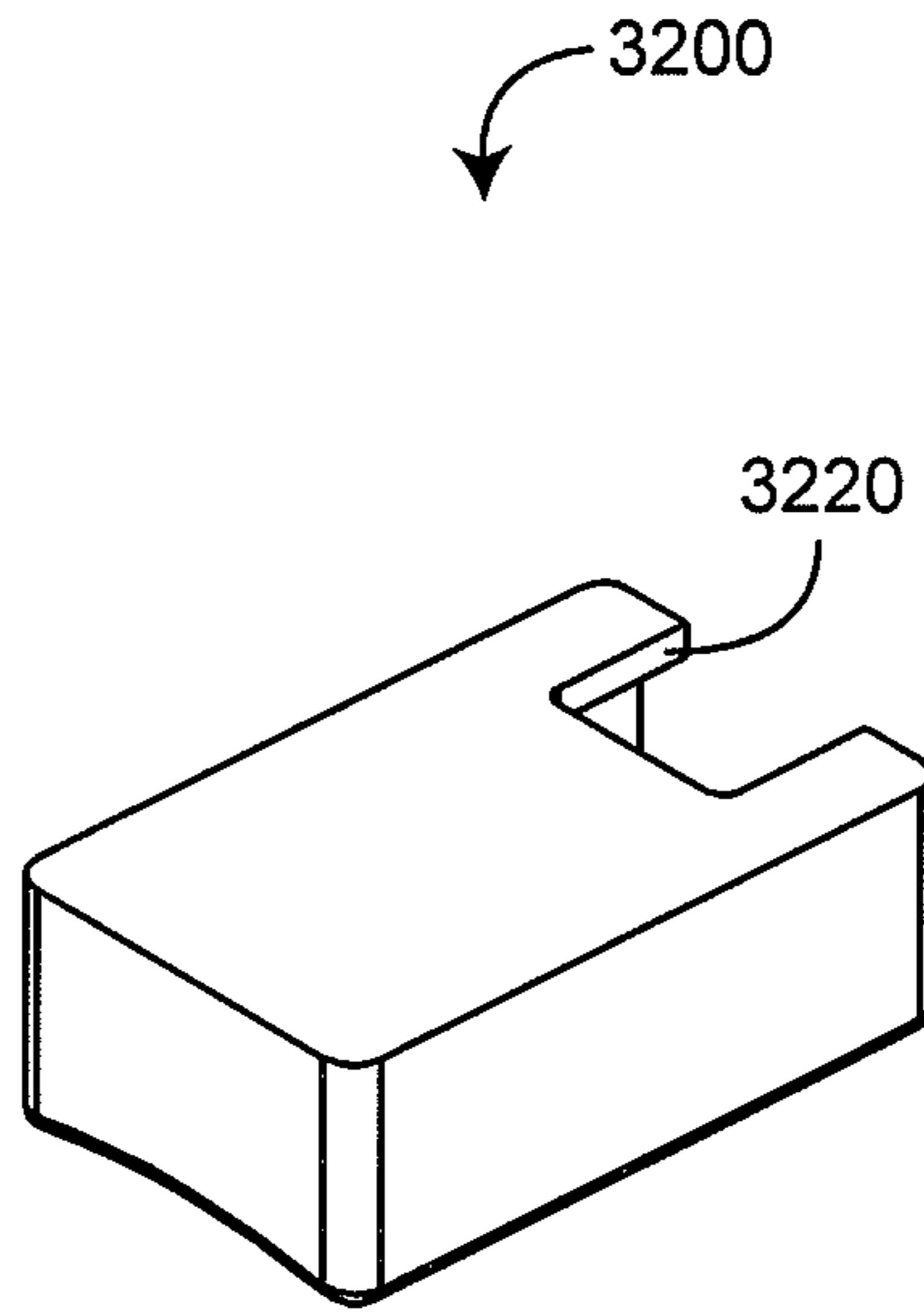


FIG. 32A

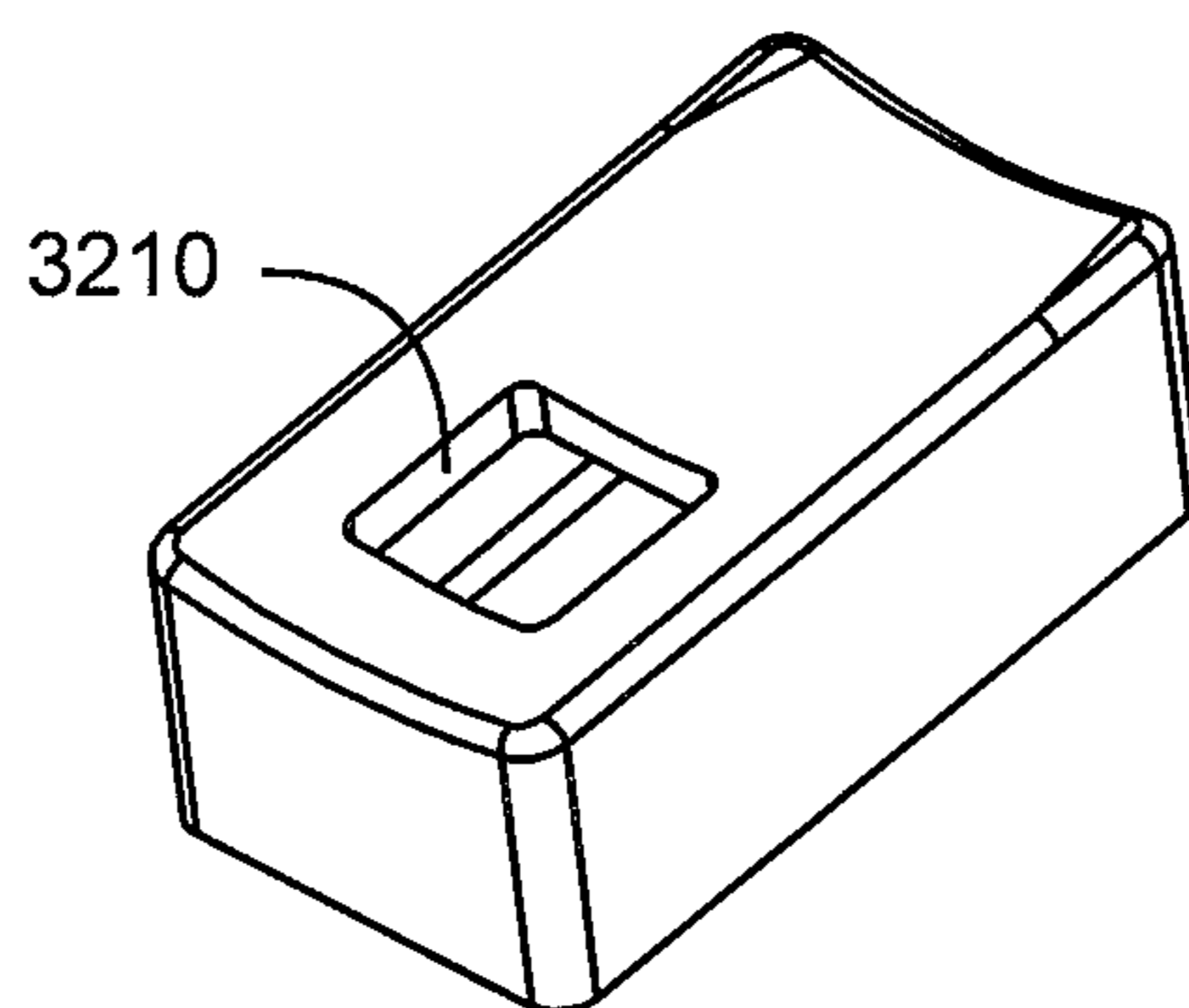


FIG. 32B

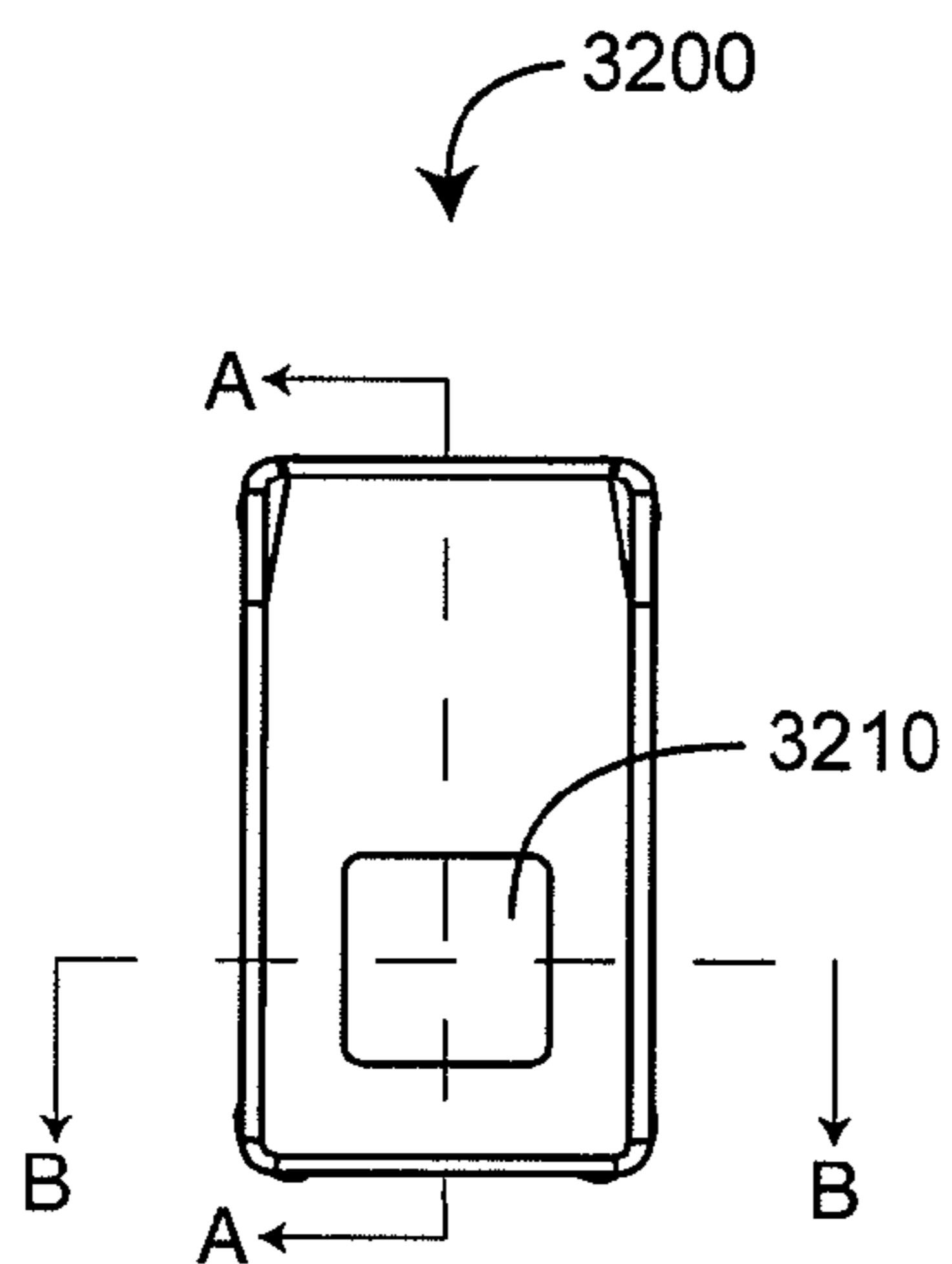
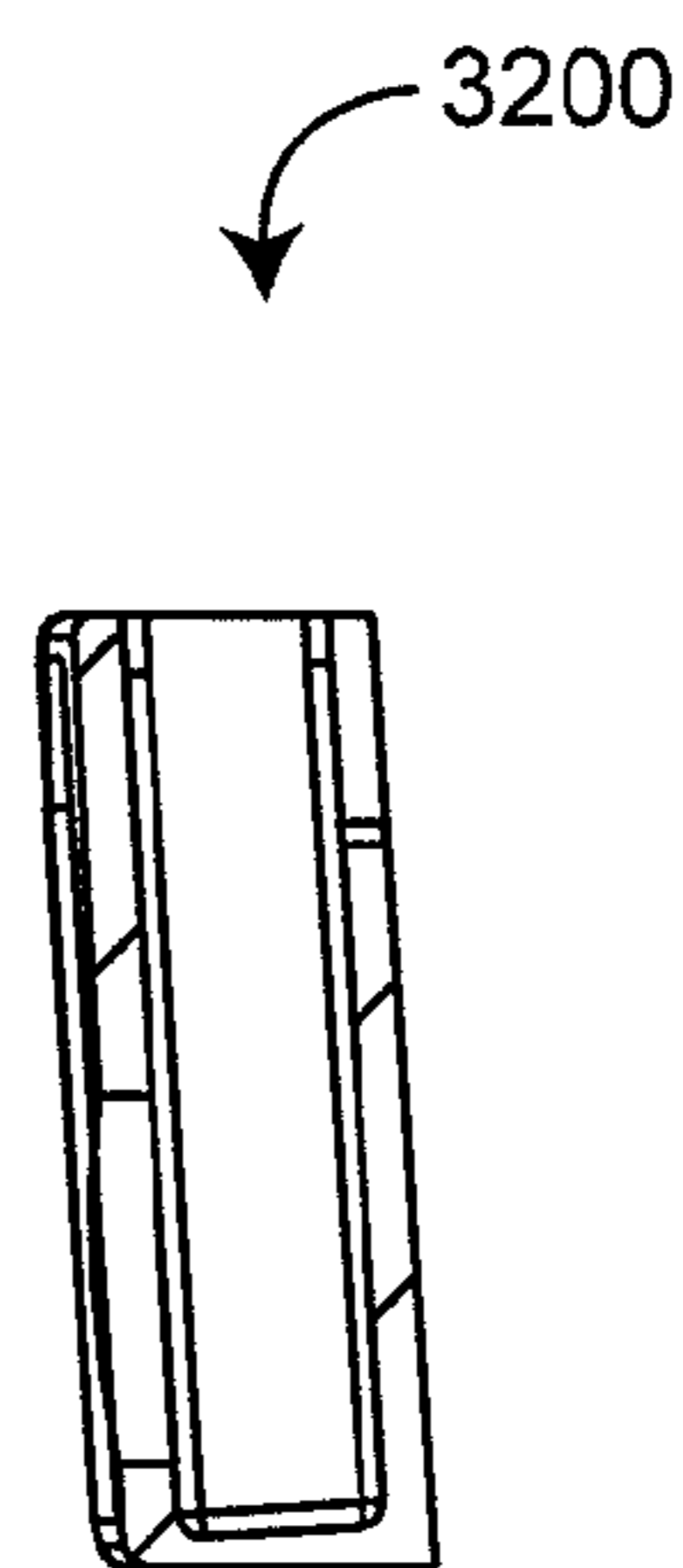


FIG. 32C



SECTION A-A
FIG. 32F

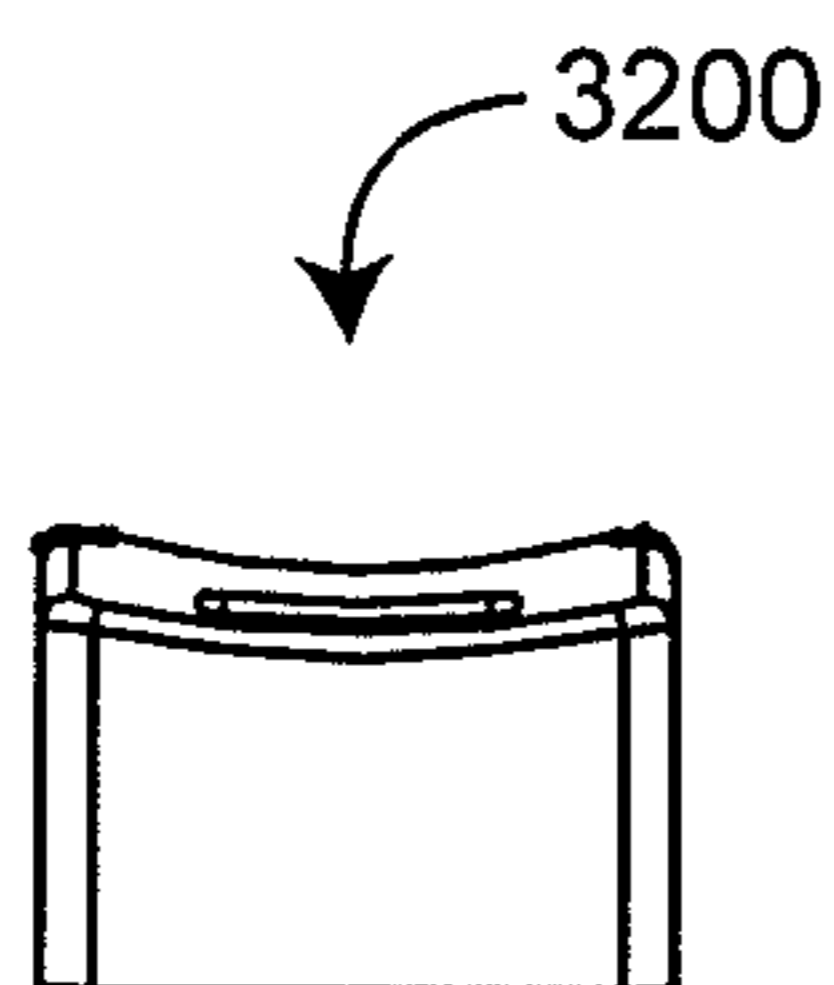


FIG. 32D

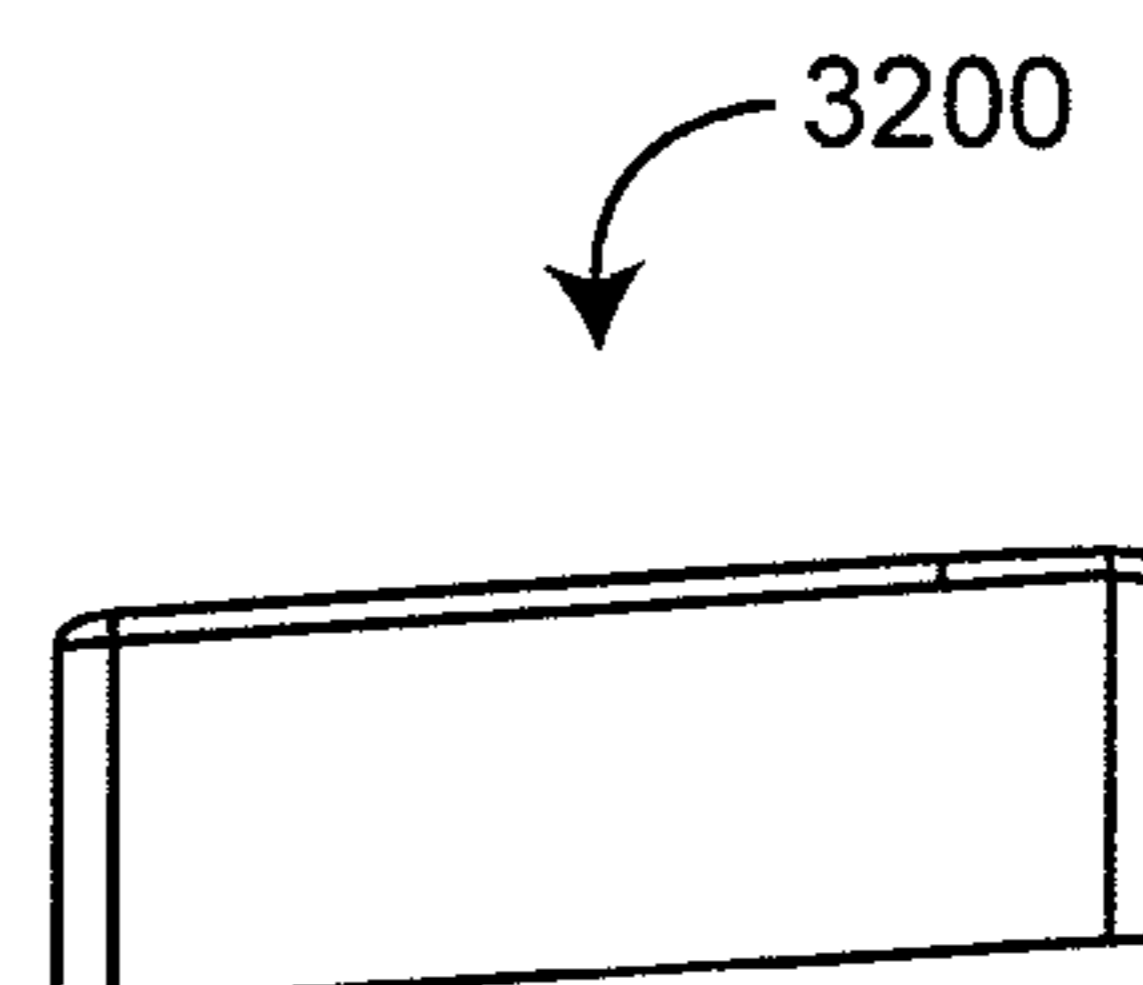


FIG. 32G

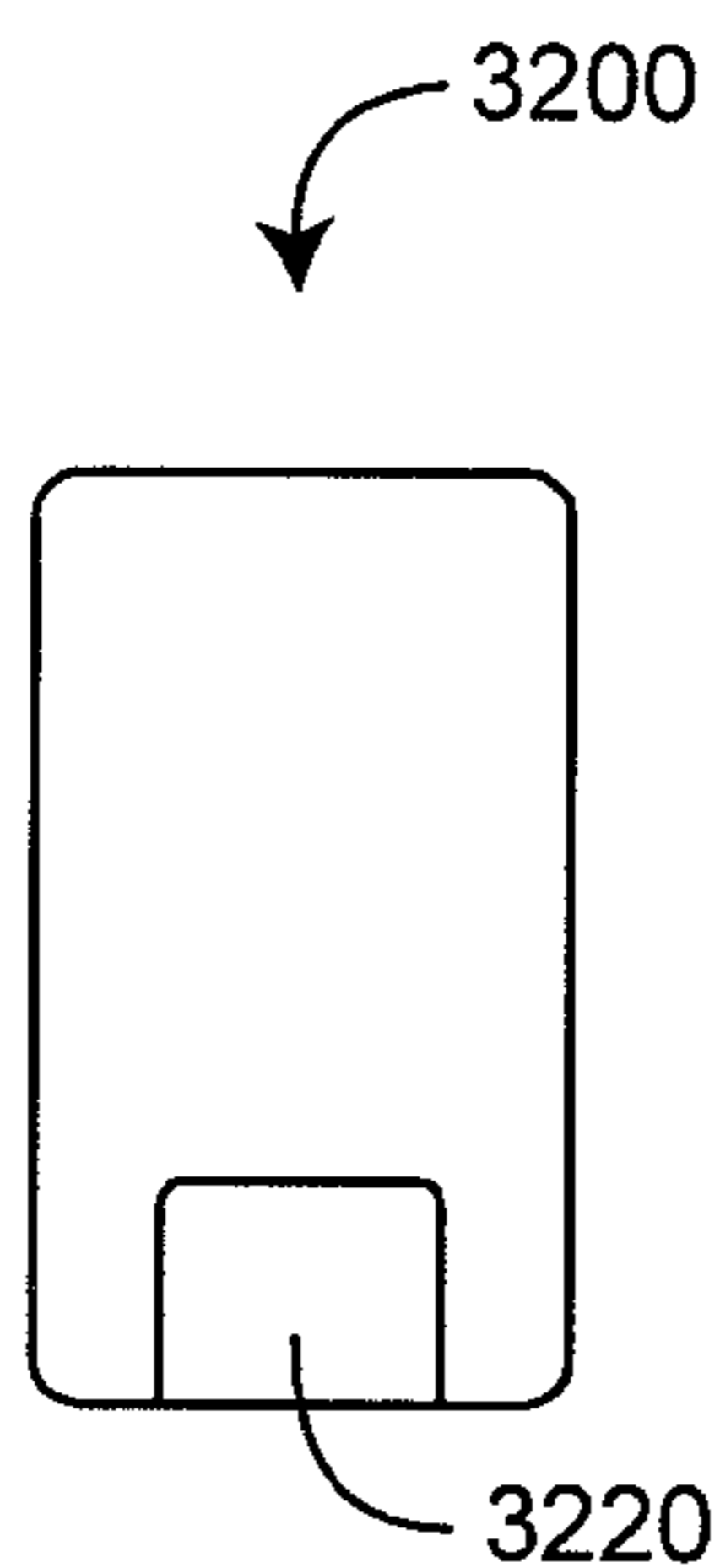
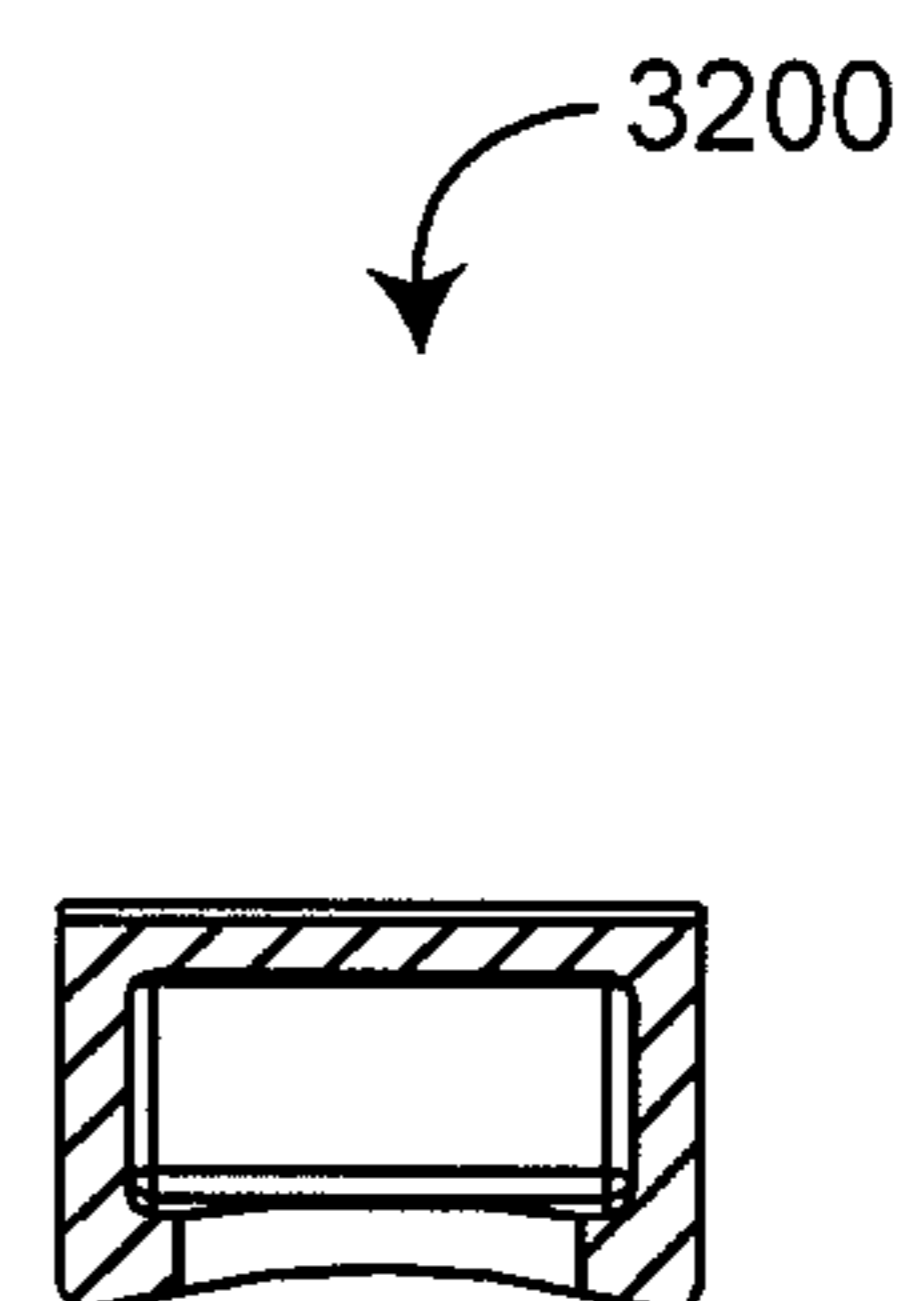


FIG. 32E



SECTION B-B
FIG. 32H

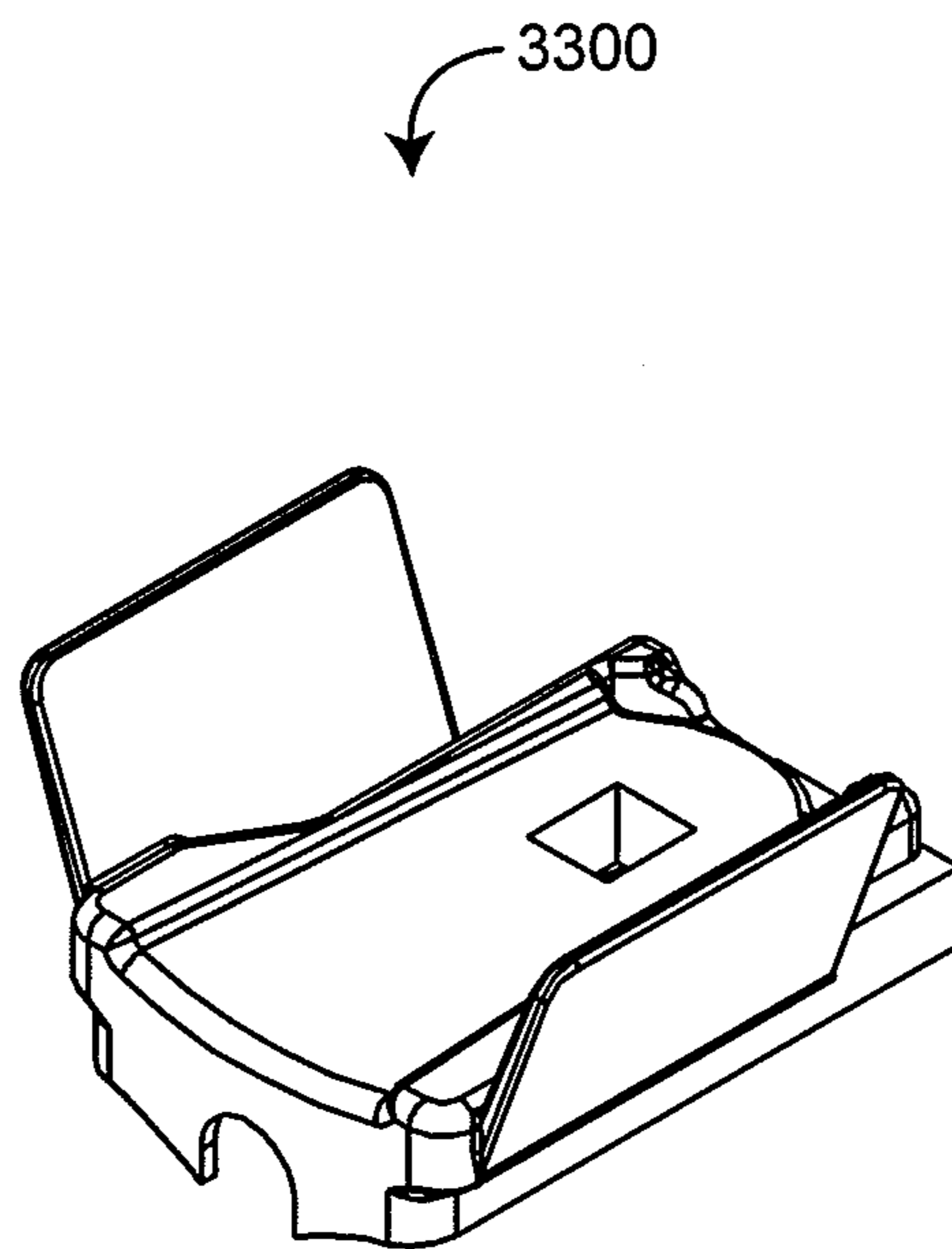


FIG. 33A

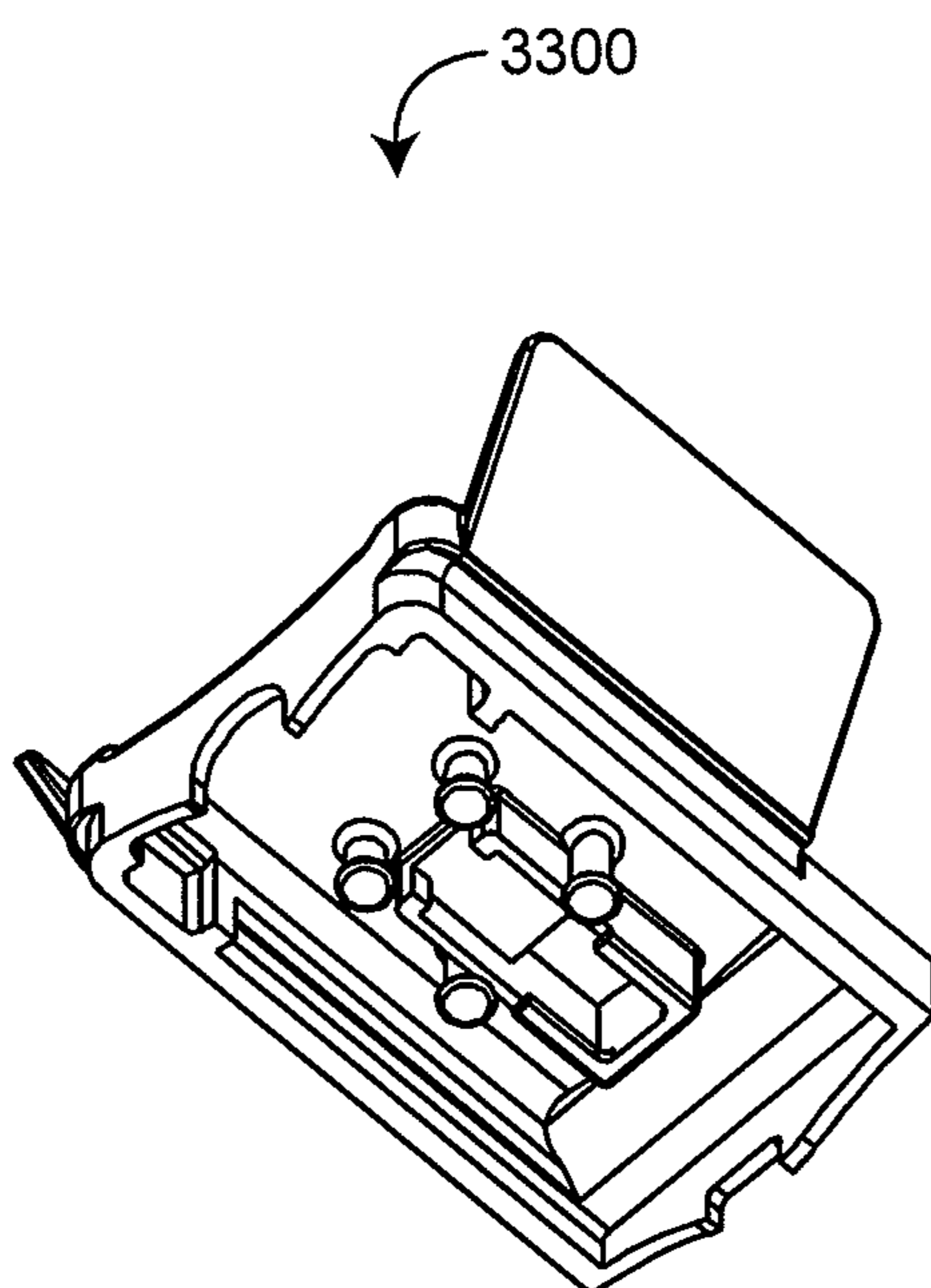


FIG. 33B

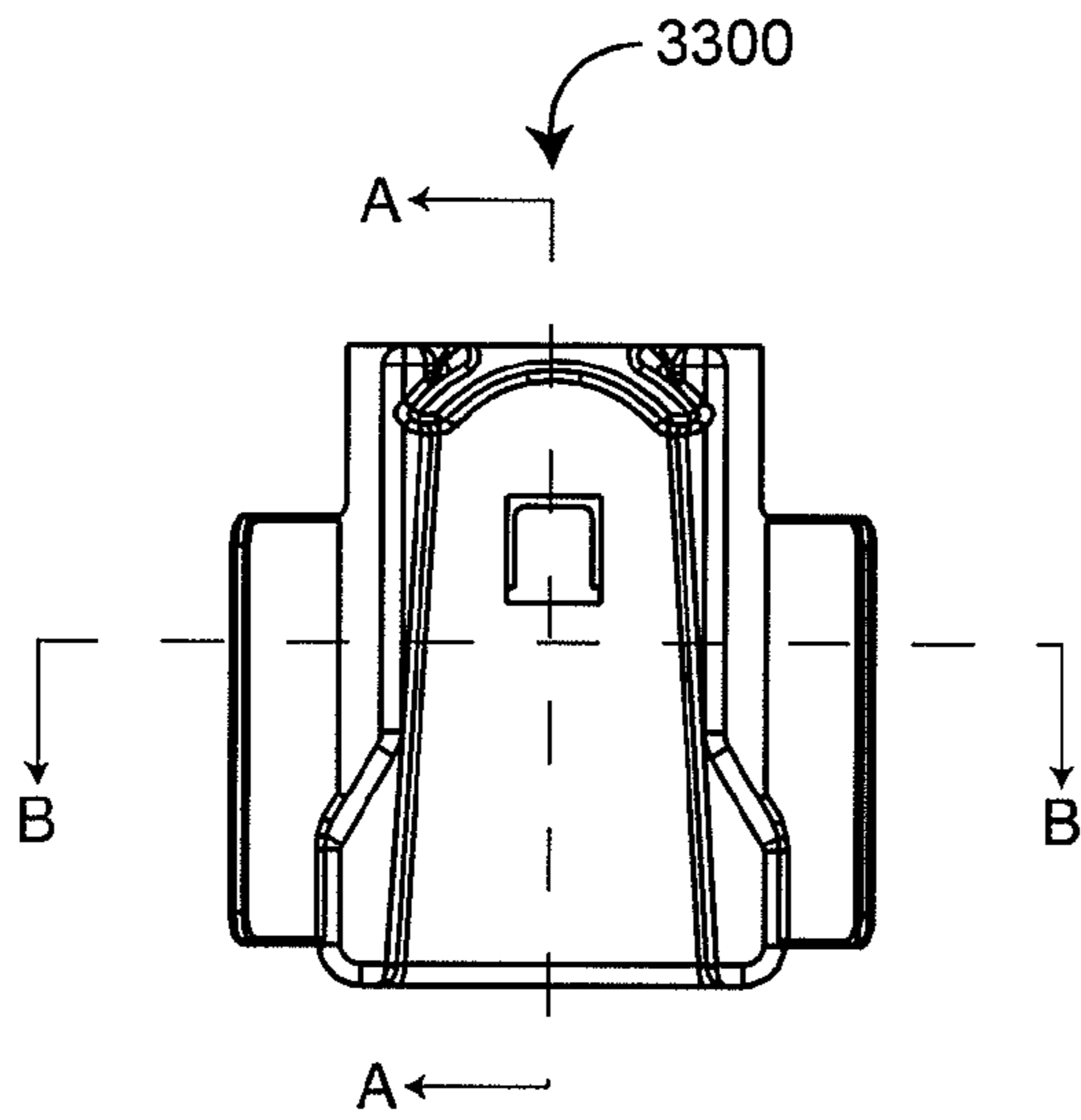
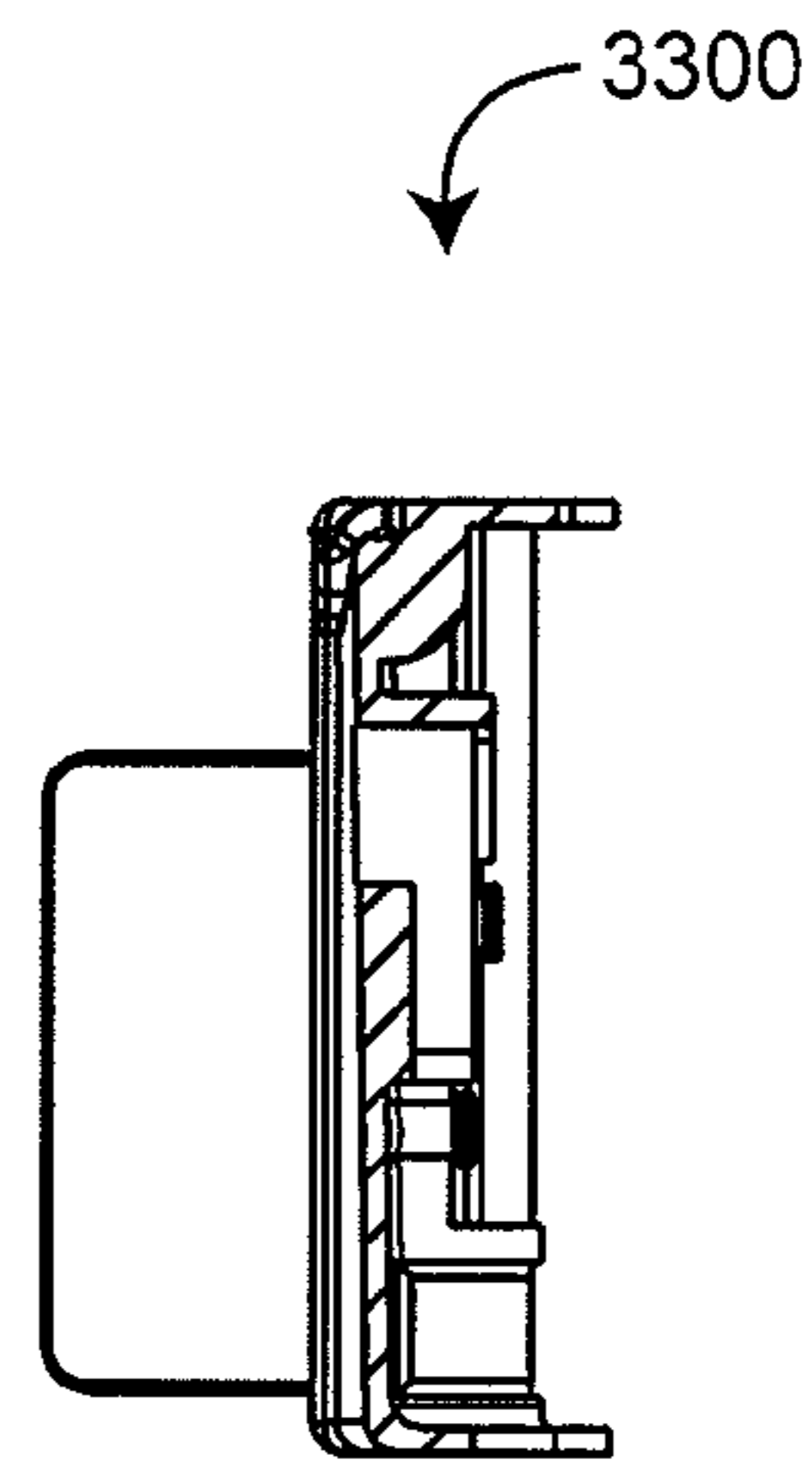


FIG. 33C



SECTION A-A

FIG. 33F

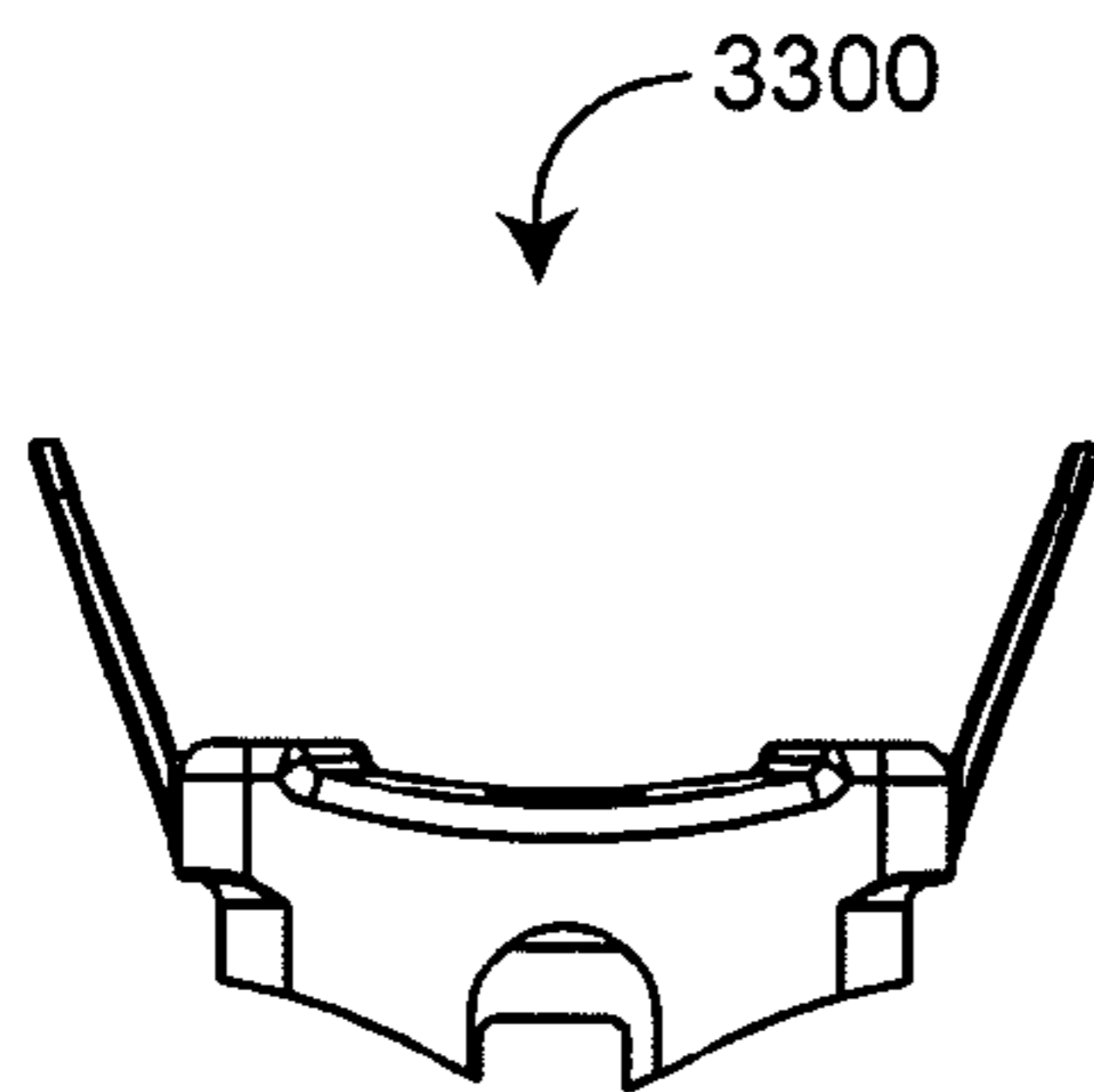


FIG. 33D

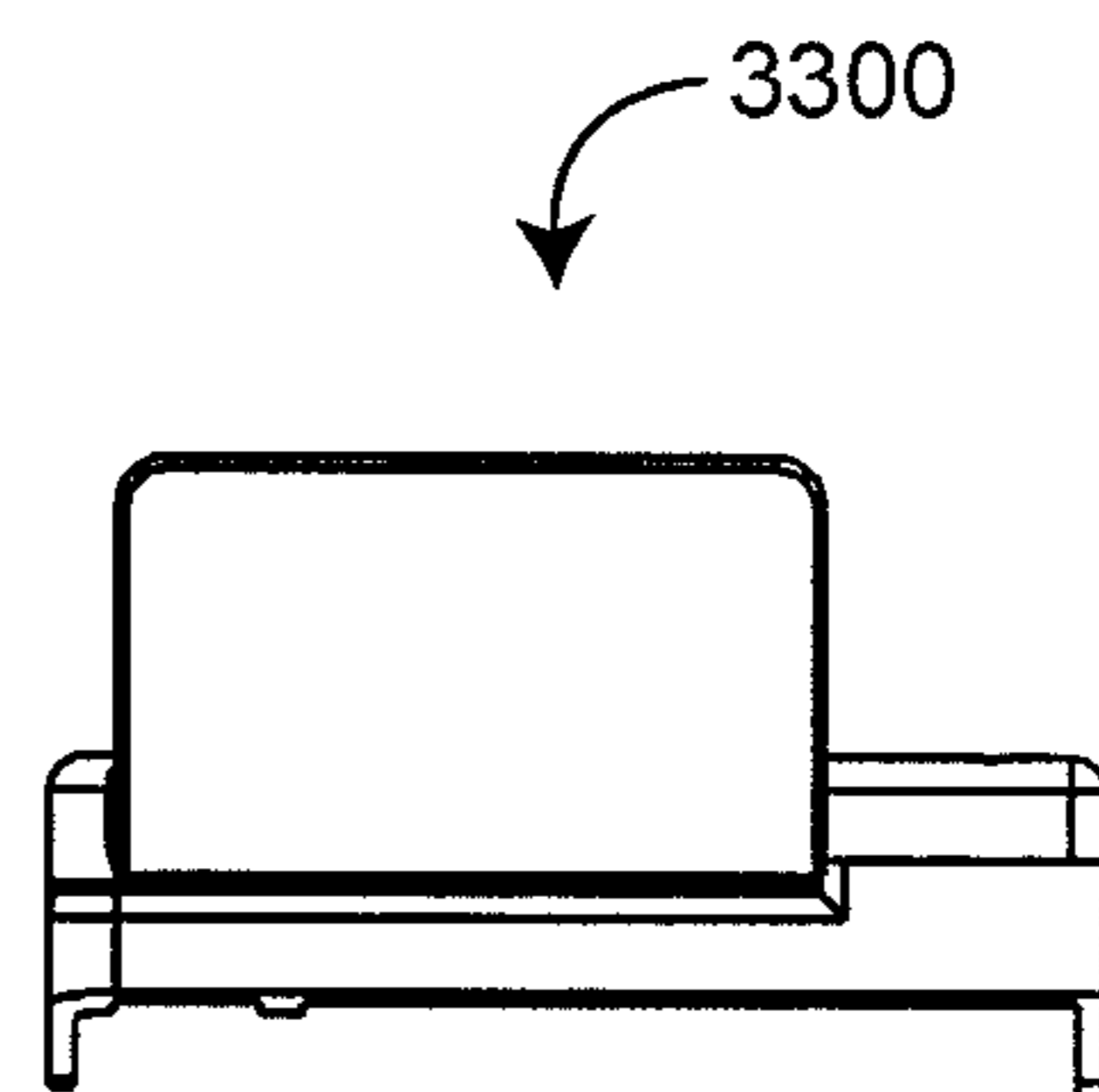


FIG. 33G

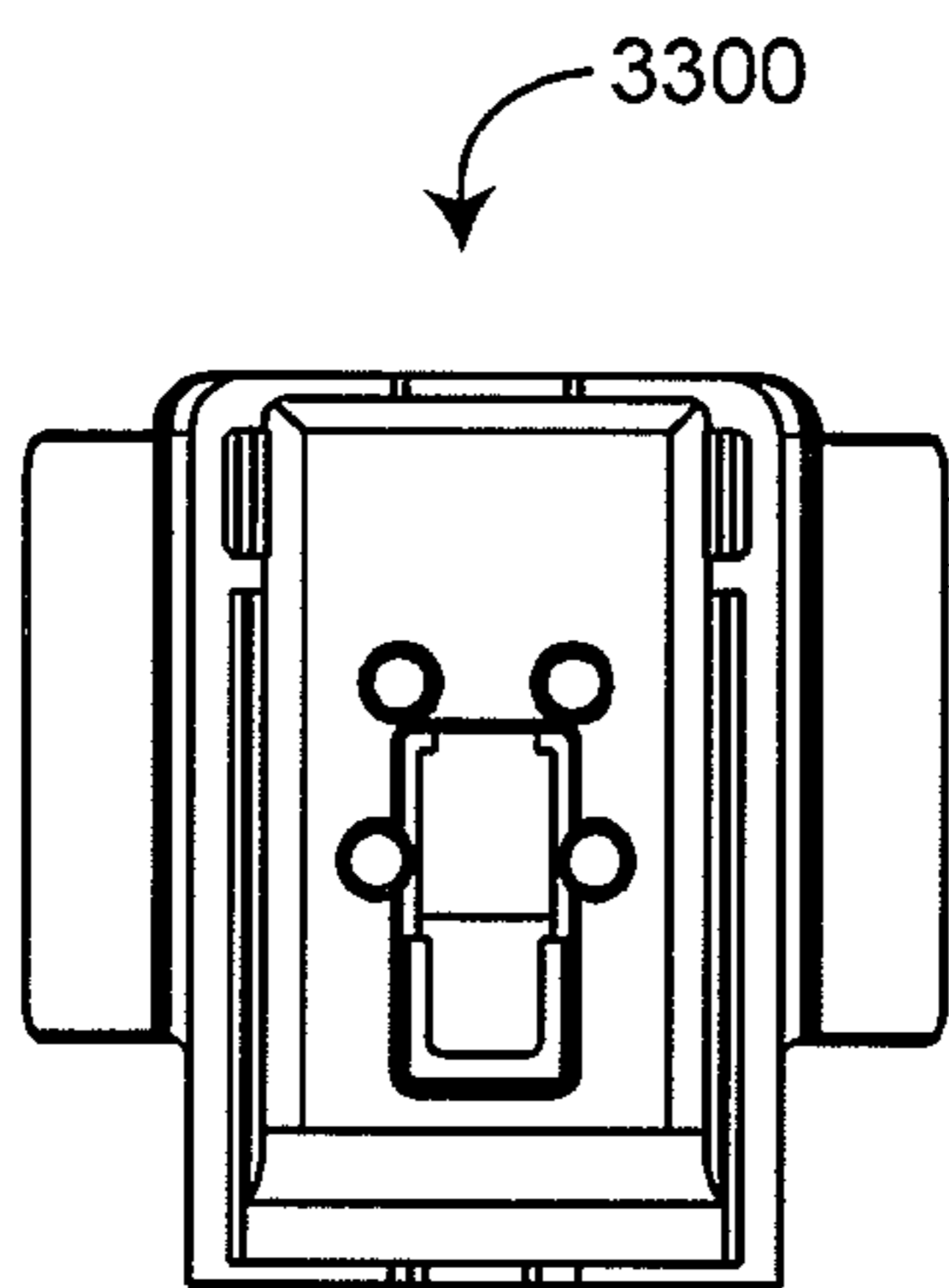
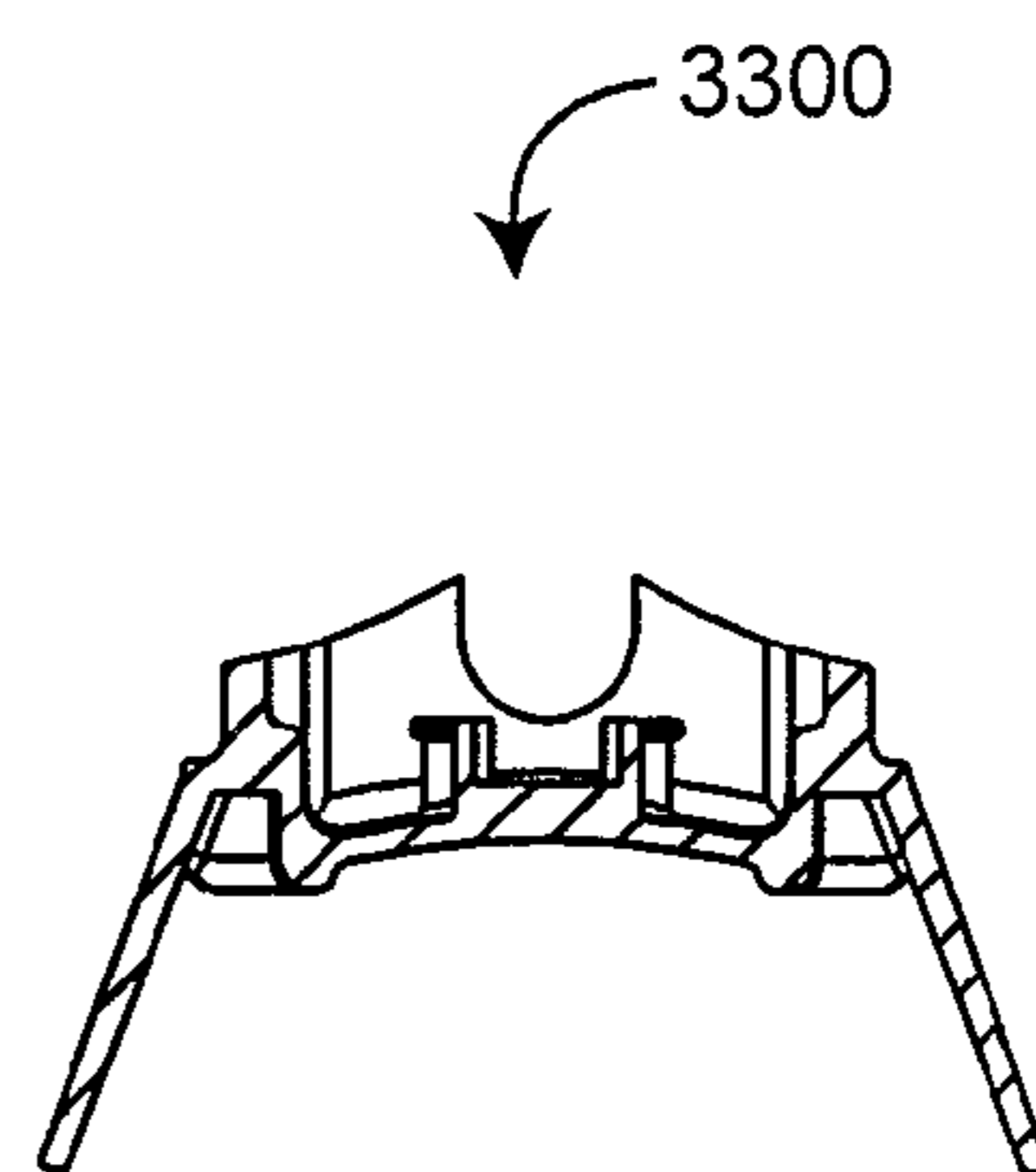


FIG. 33E



SECTION B-B

FIG. 33H

3400

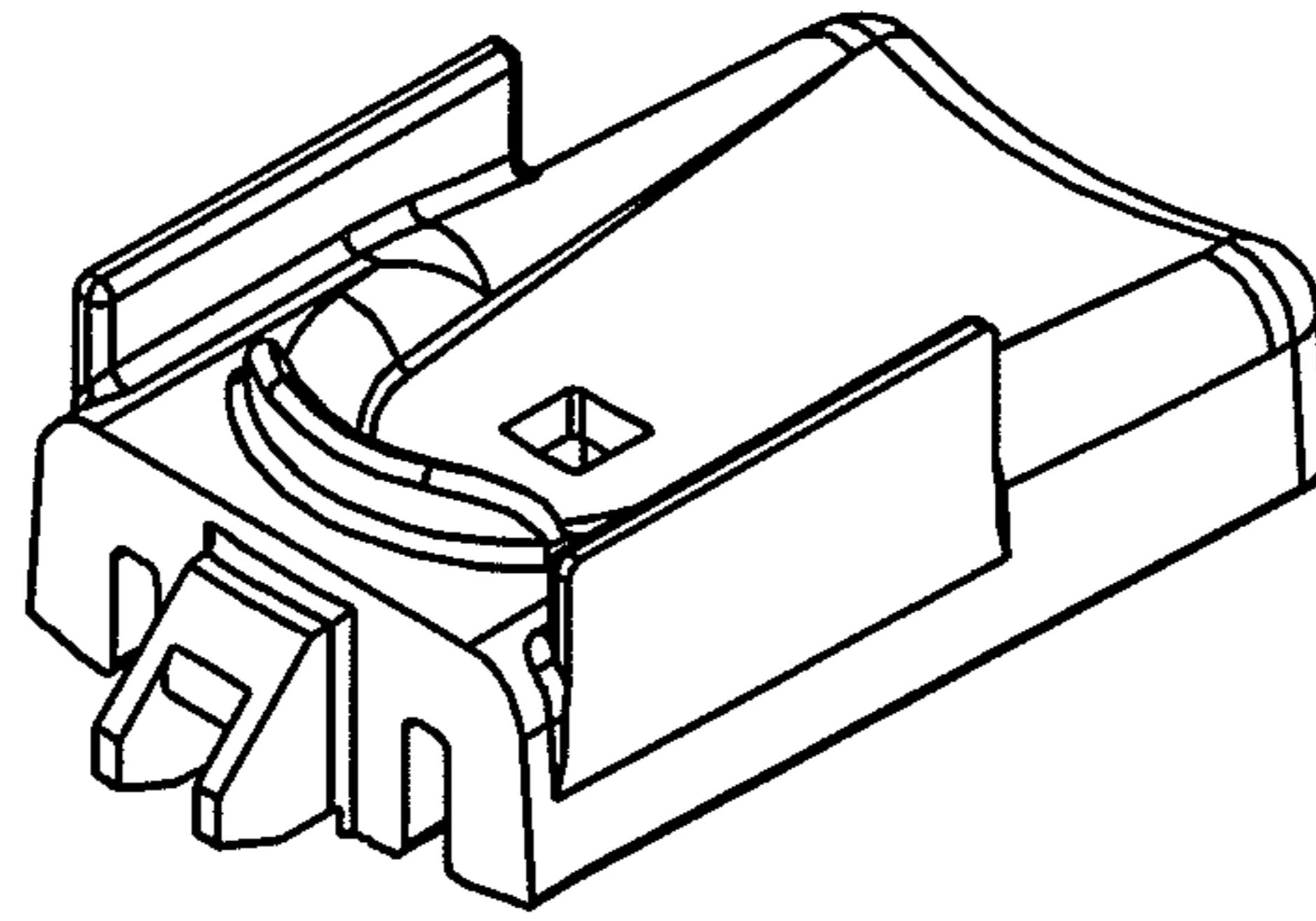


FIG. 34A

3400

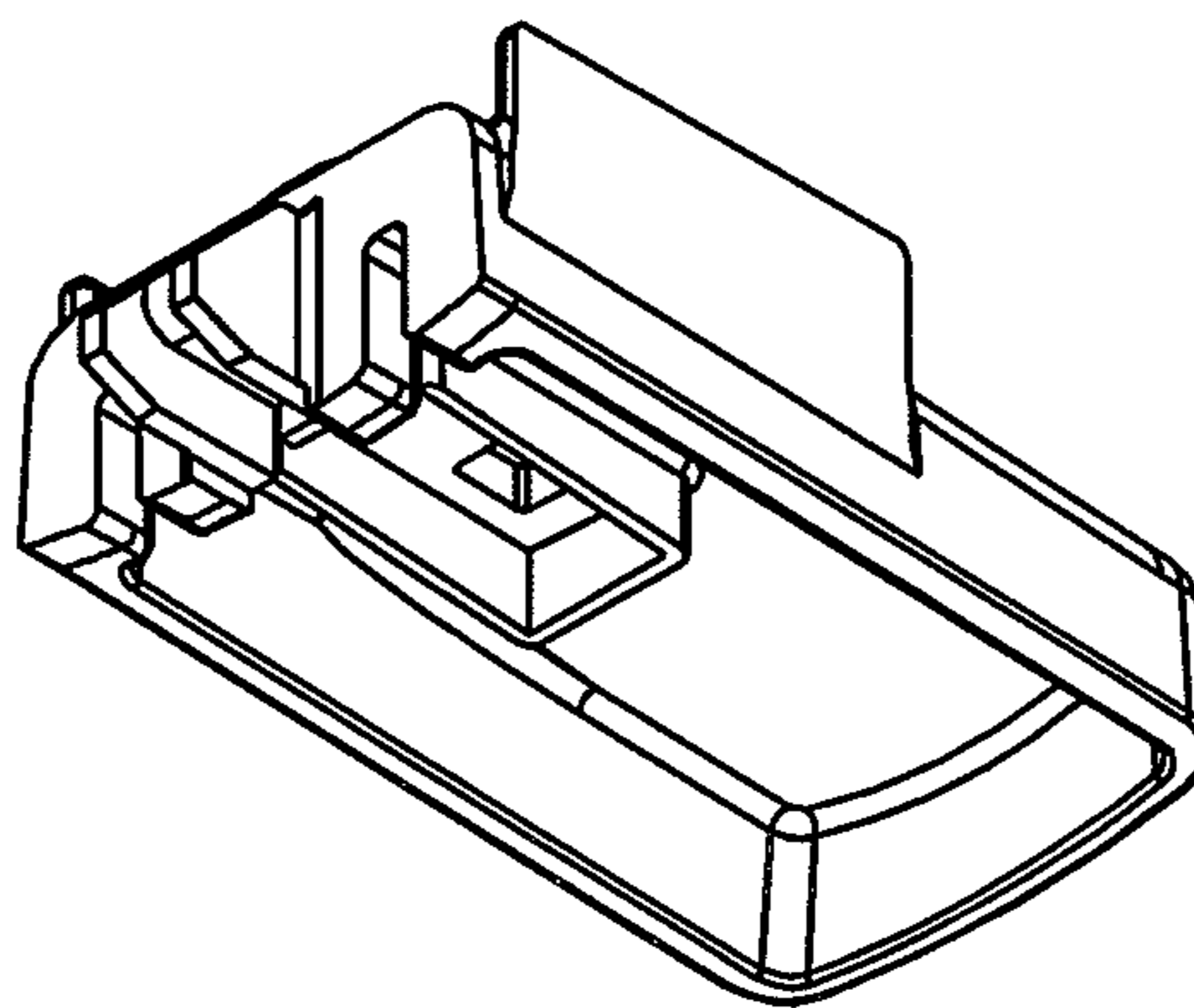


FIG. 34B

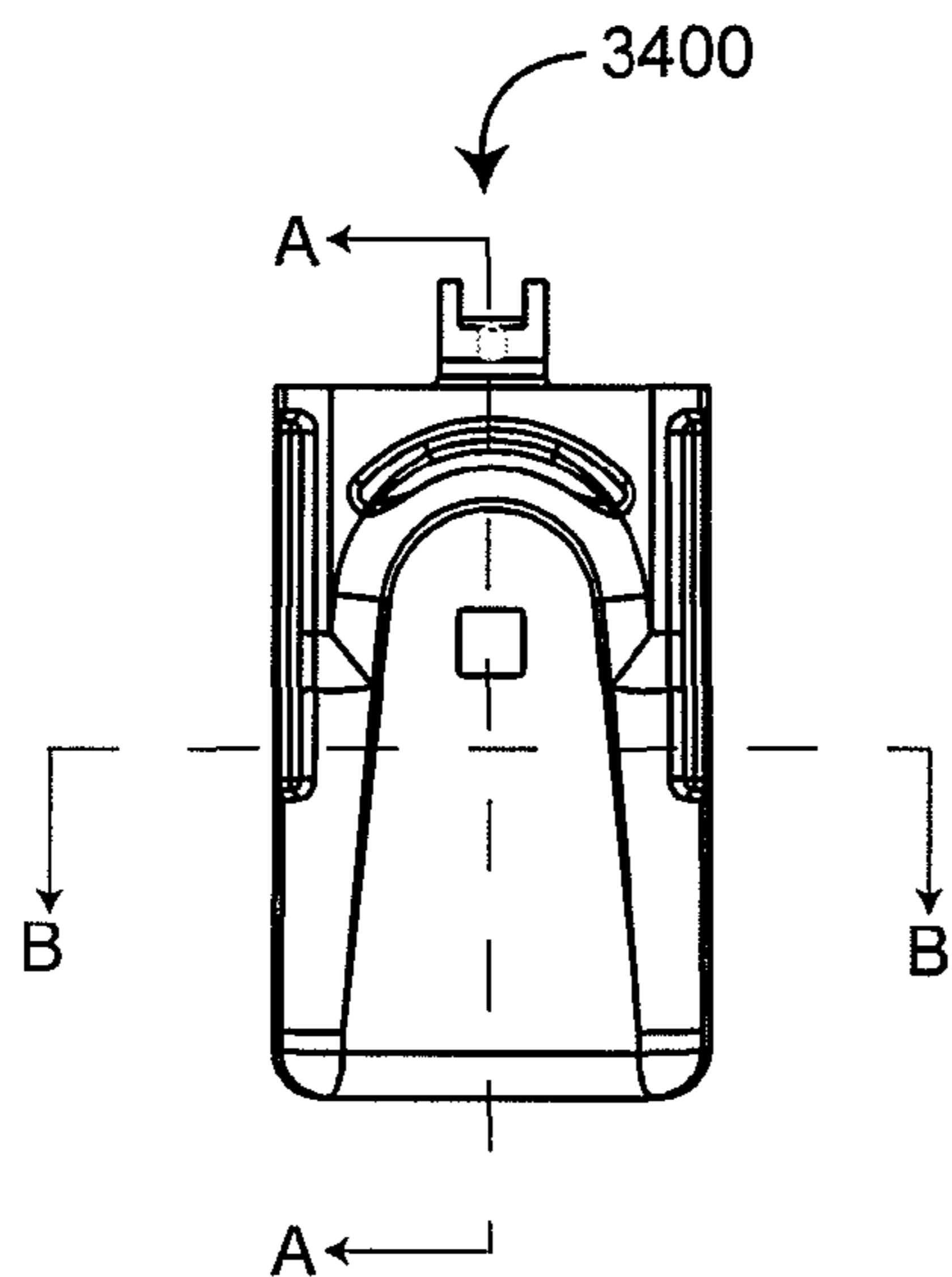
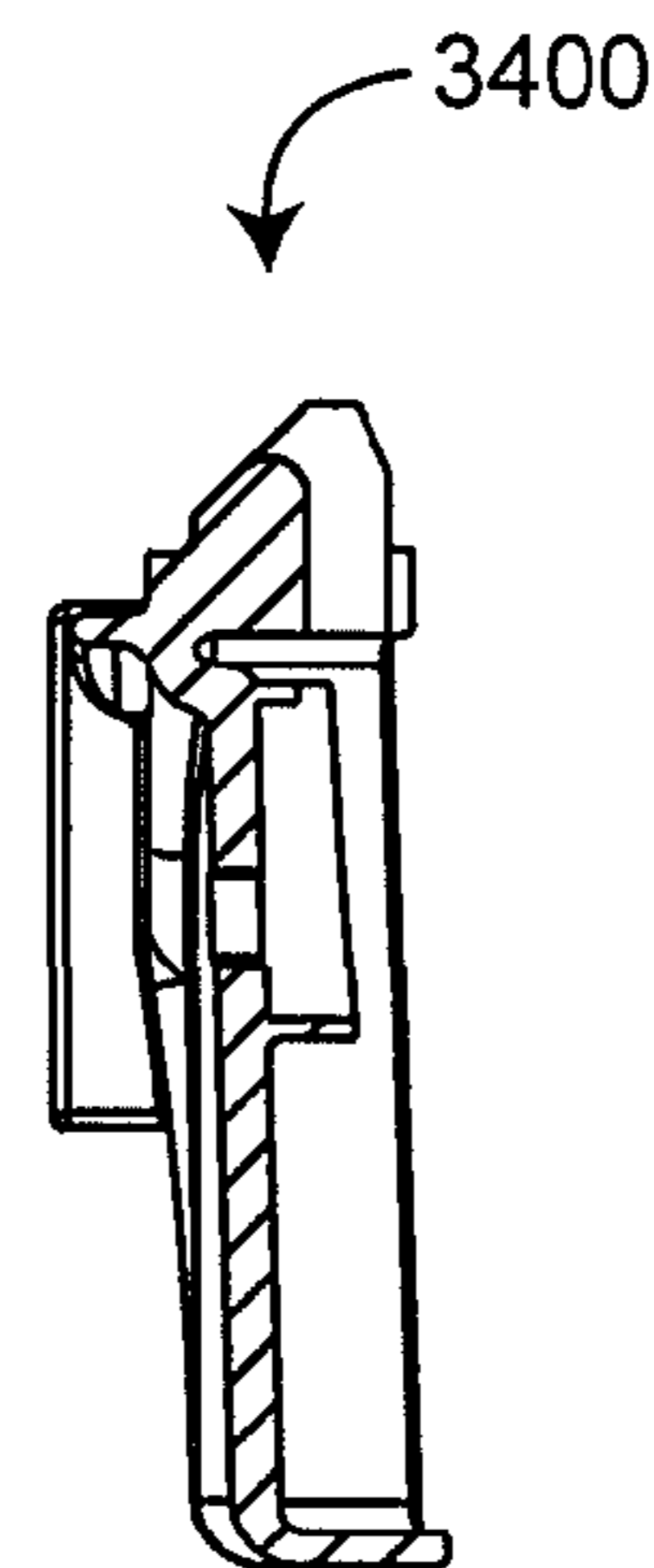


FIG. 34C



SECTION A-A

FIG. 34F

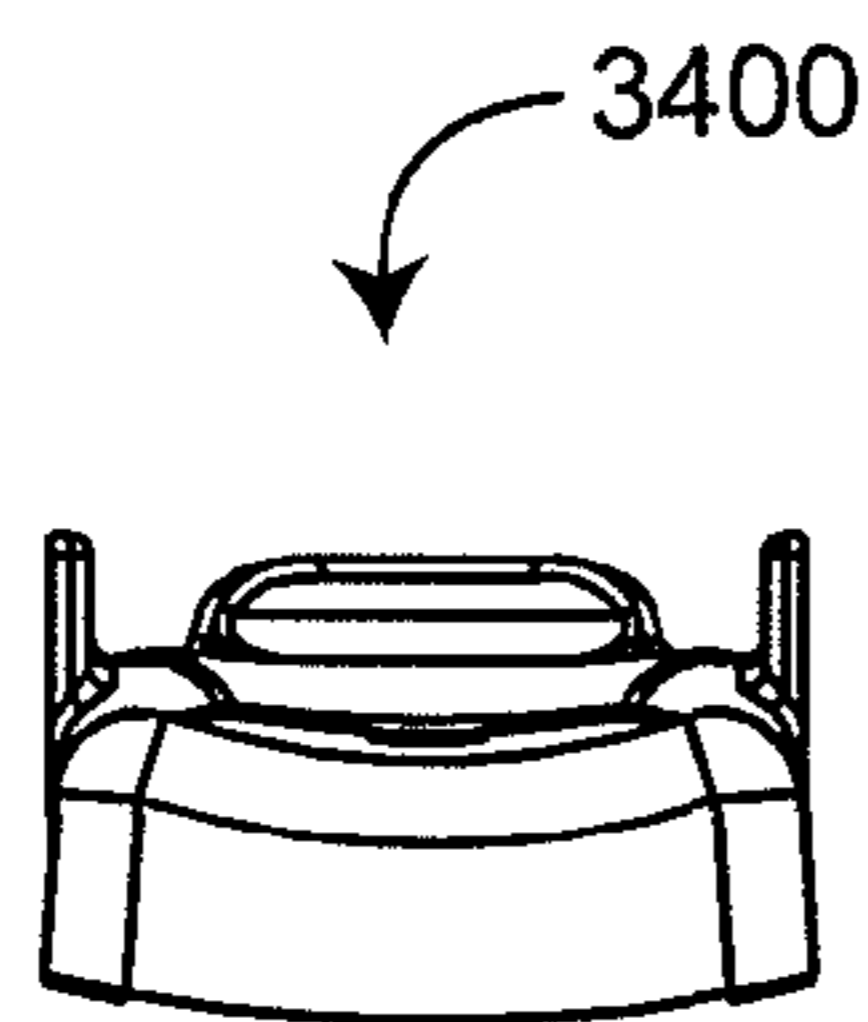


FIG. 34D

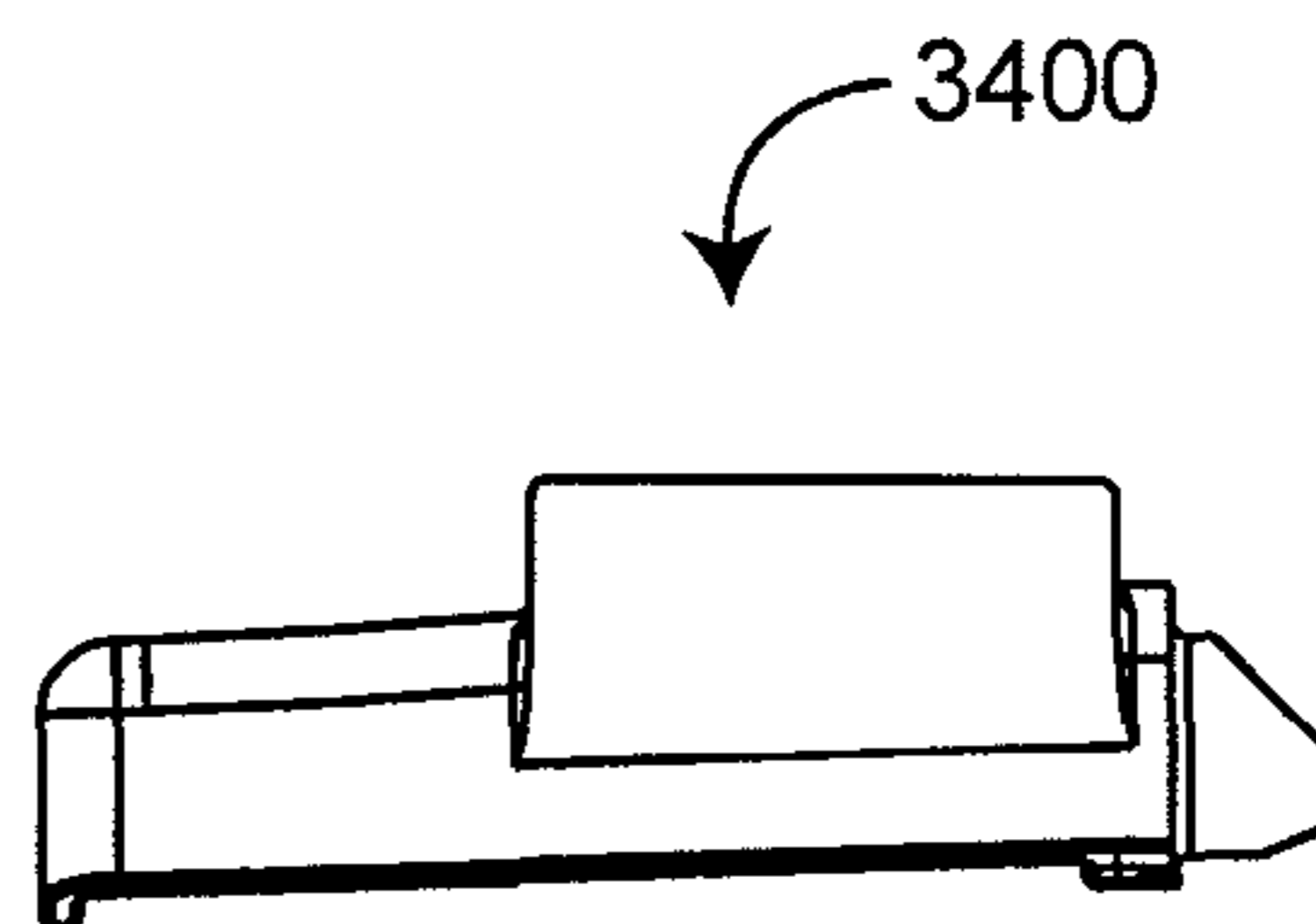


FIG. 34G

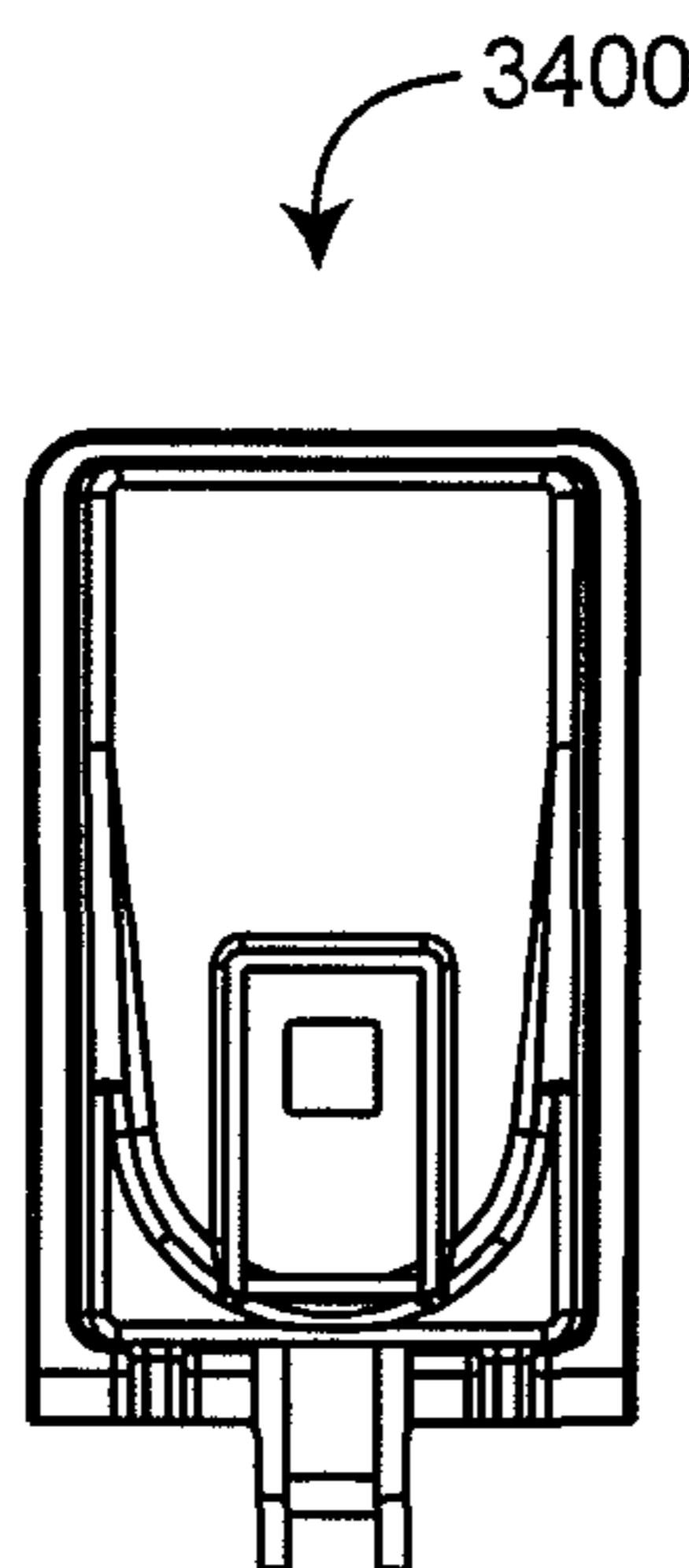
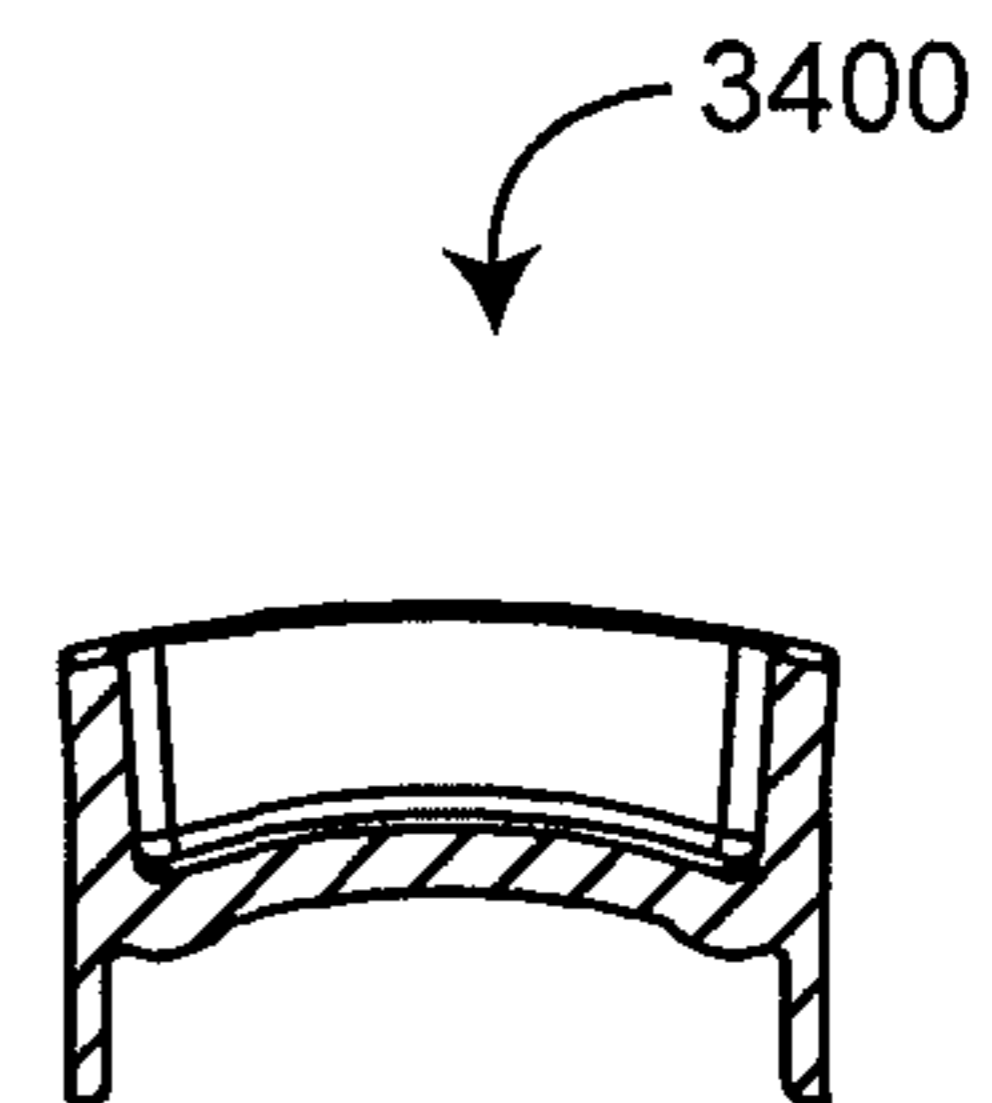


FIG. 34E



SECTION B-B

FIG. 34H

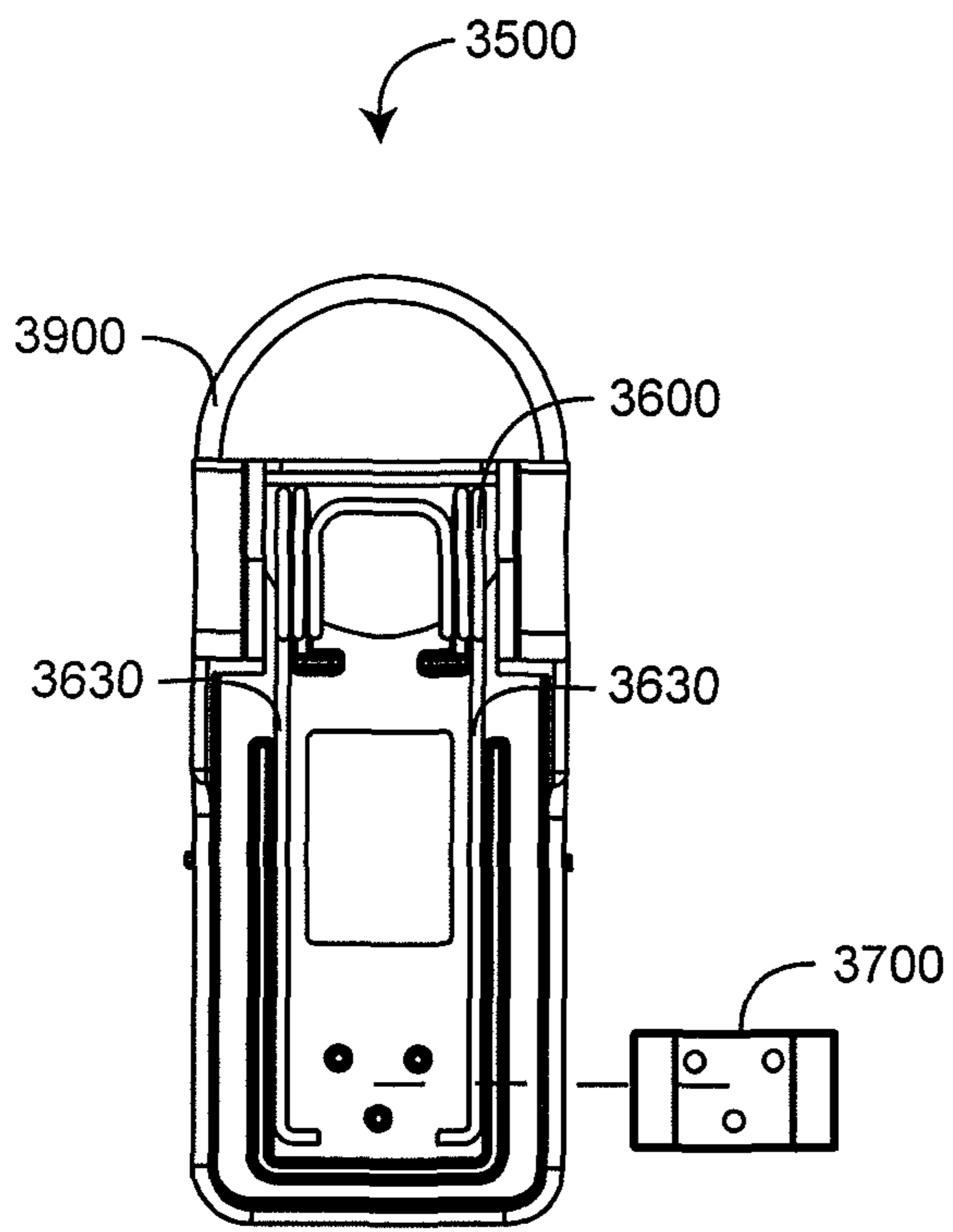


FIG. 35A

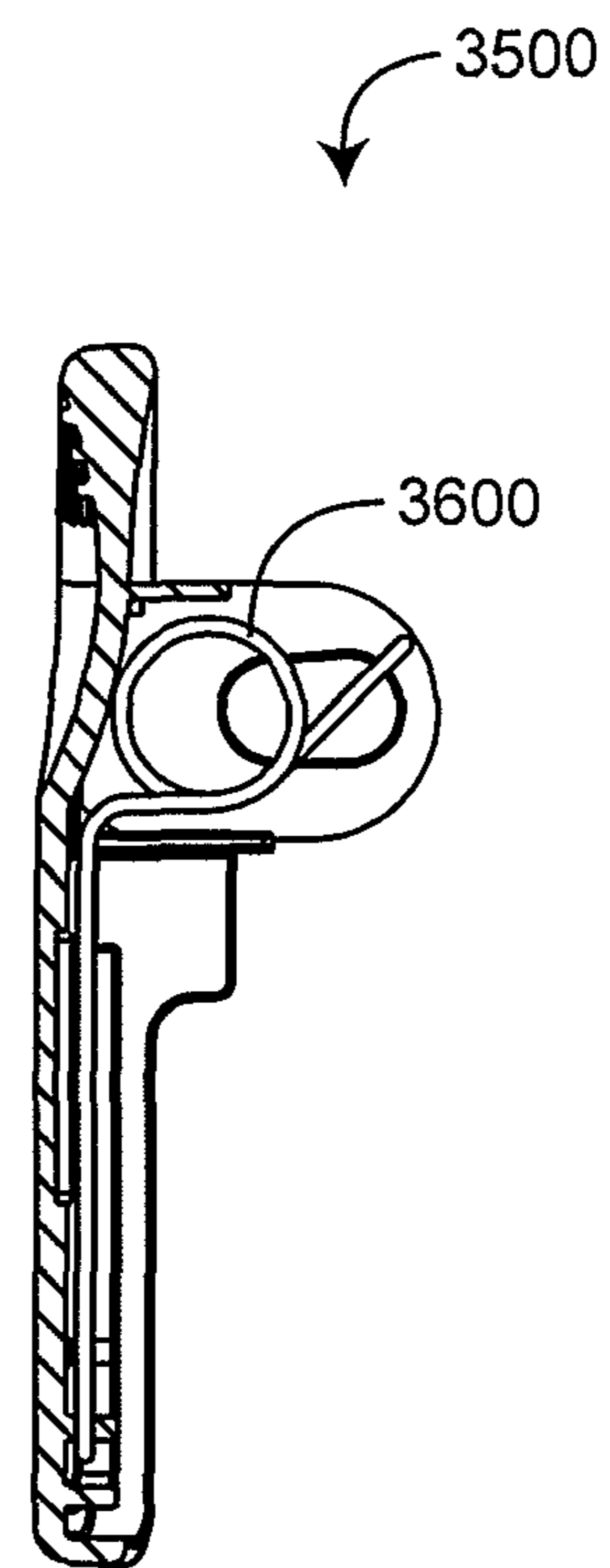


FIG. 35B

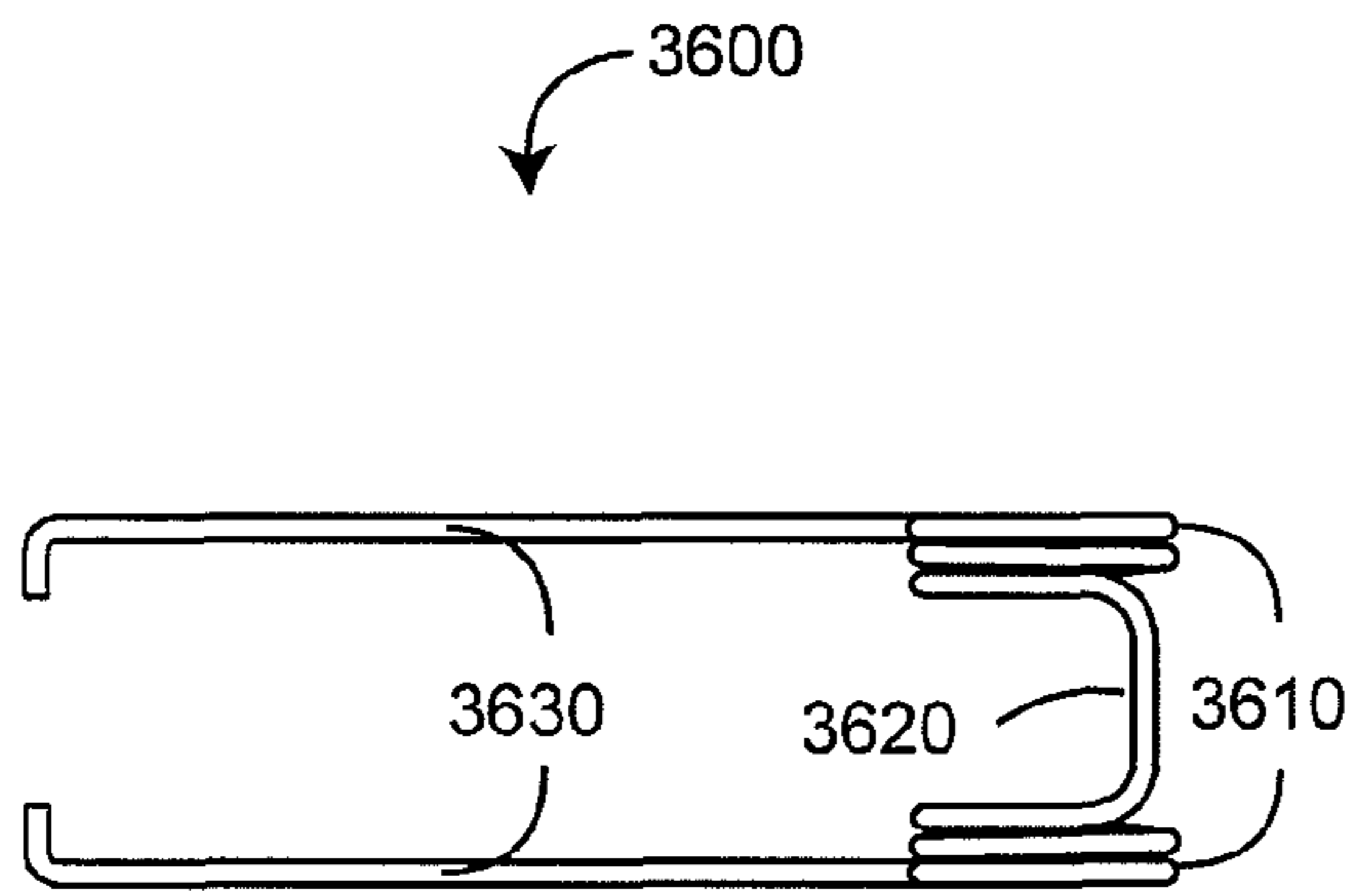


FIG. 36A

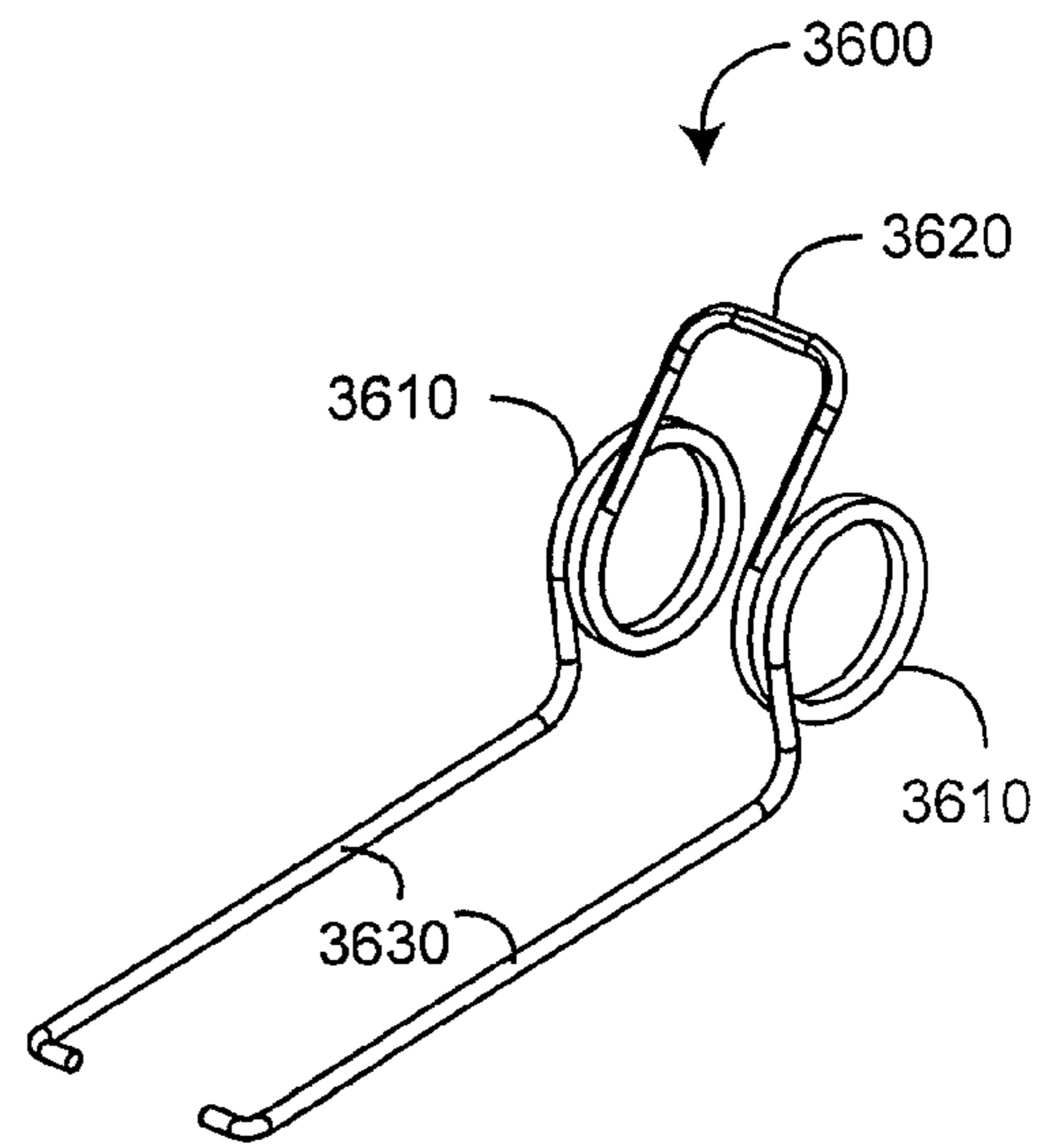


FIG. 36B

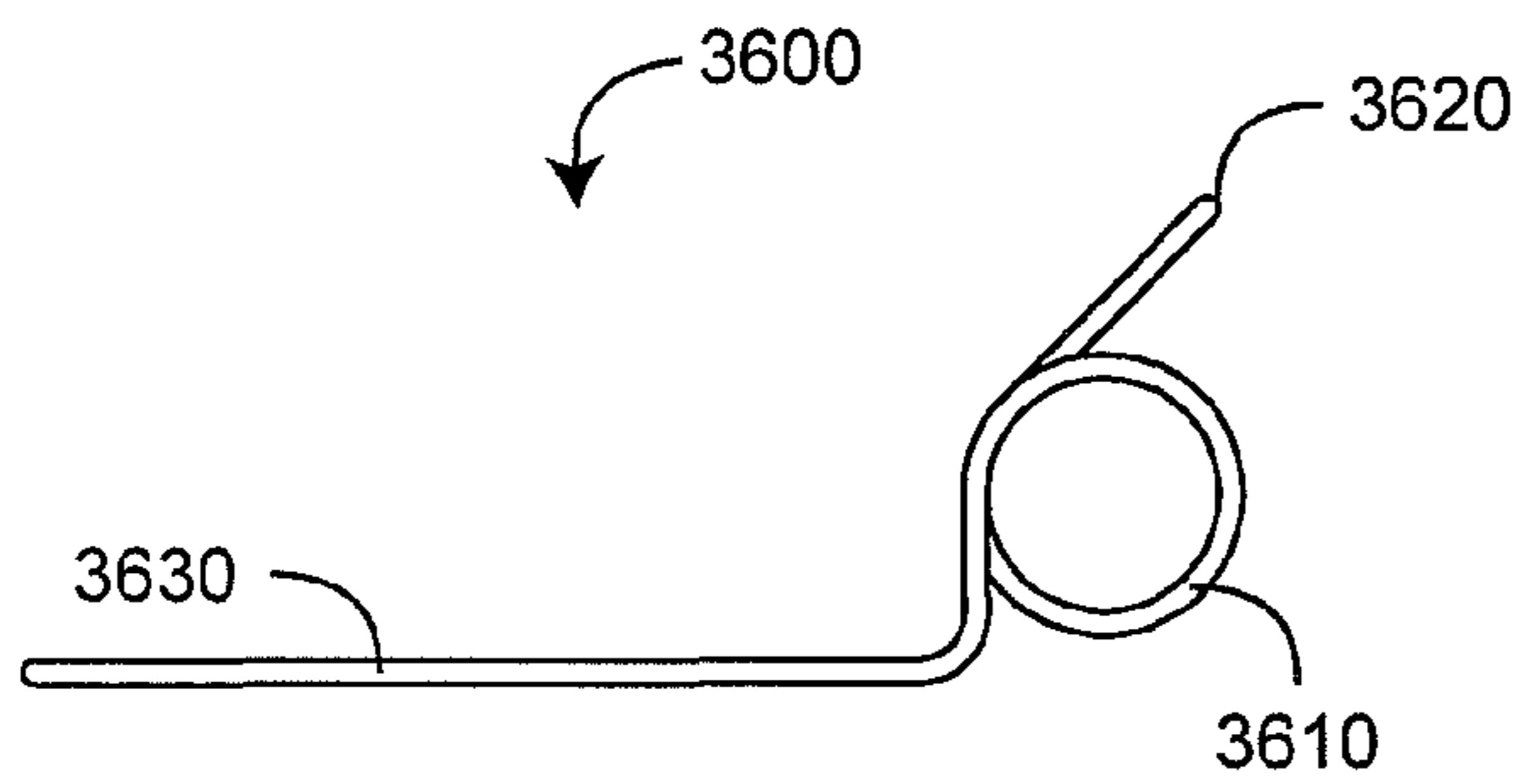


FIG. 36C

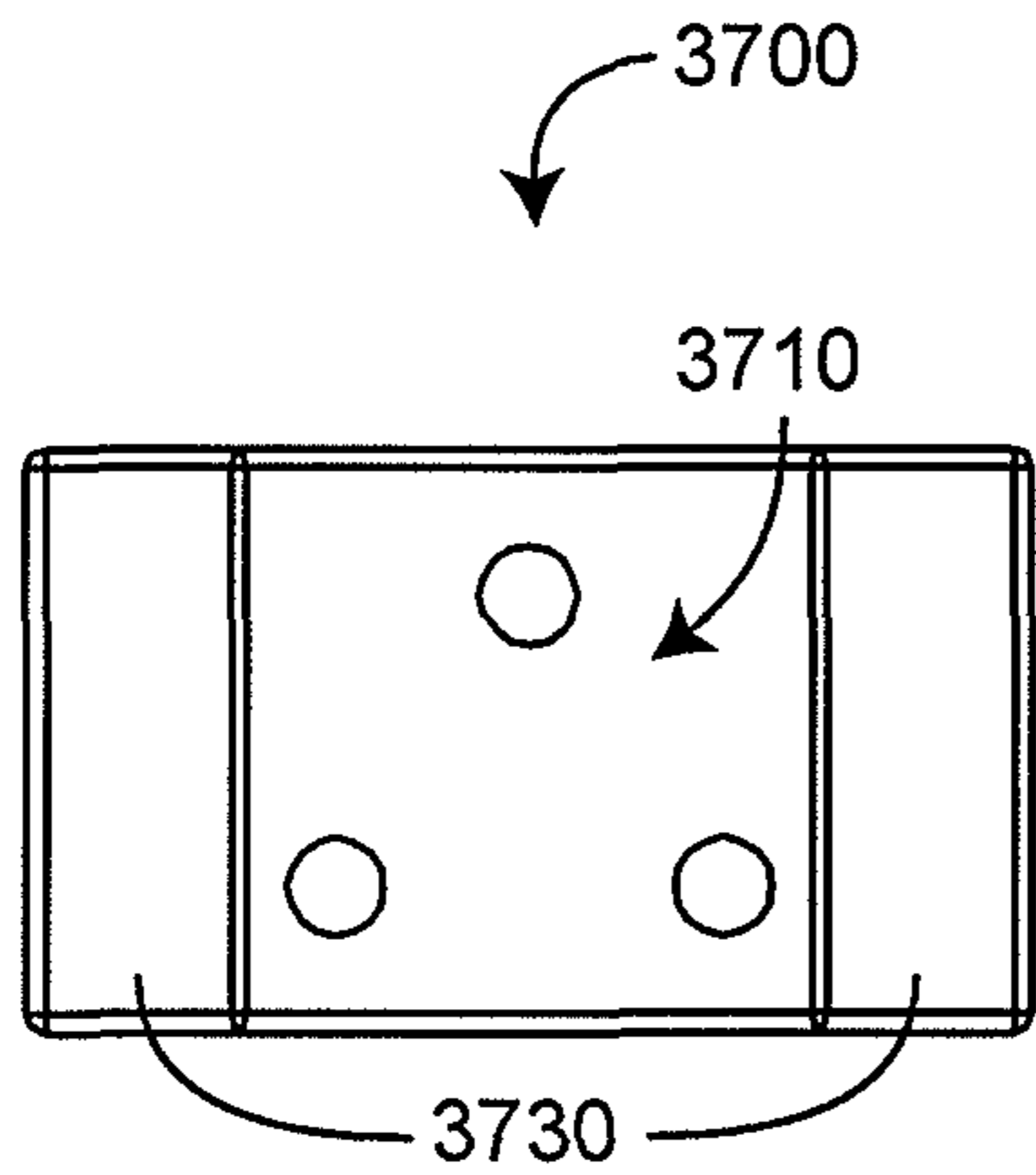


FIG. 37A

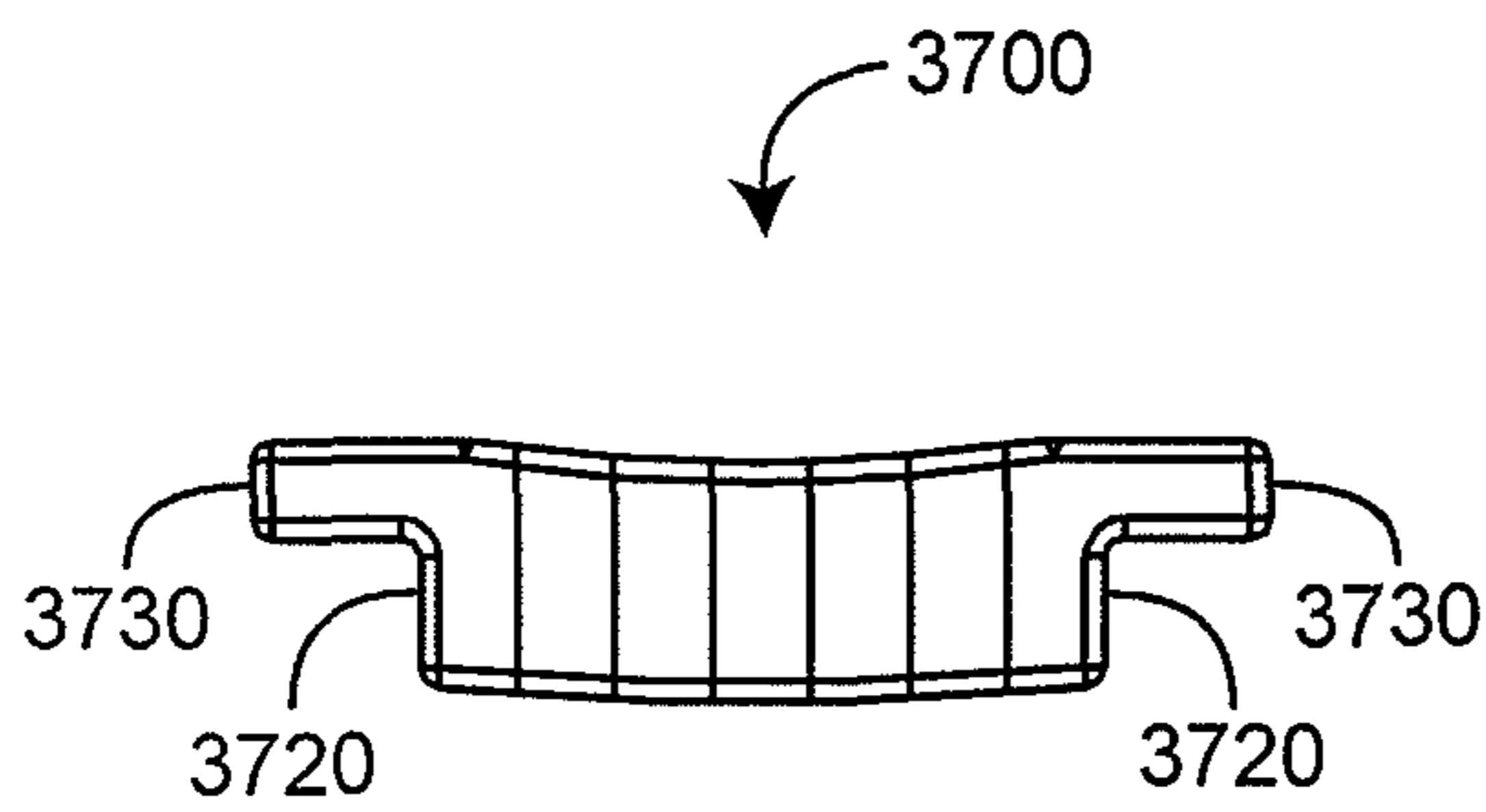


FIG. 37B

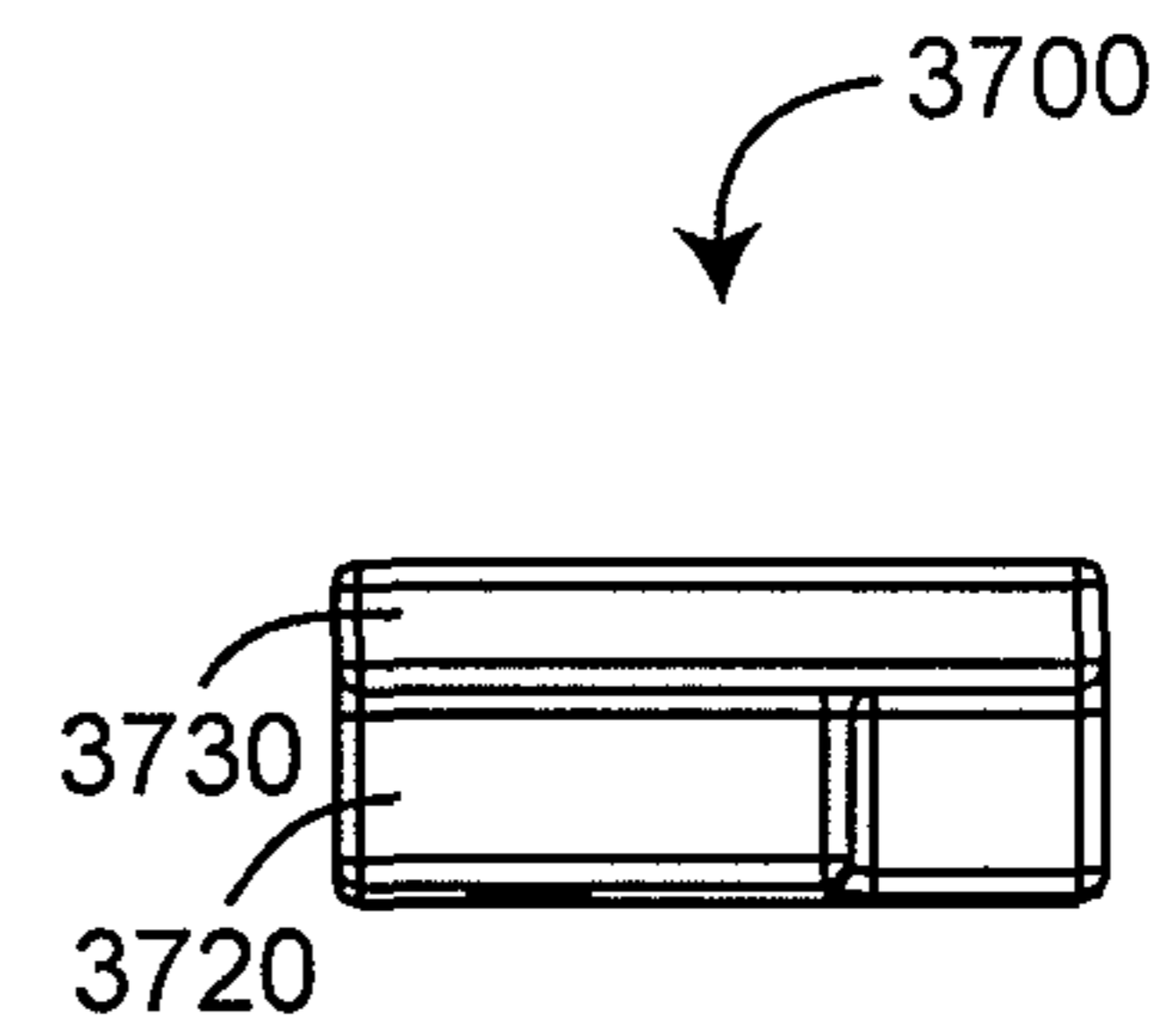


FIG. 37D

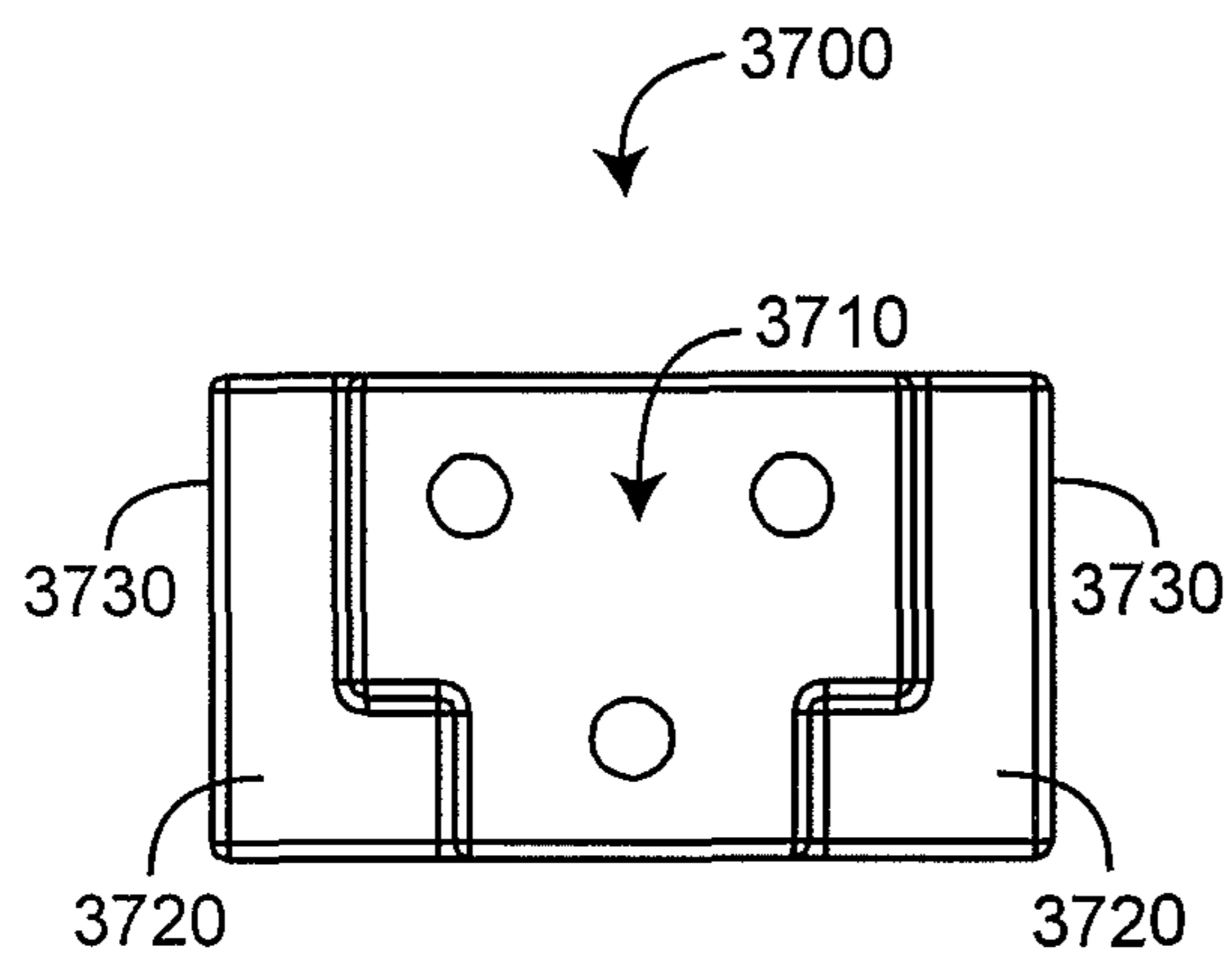


FIG. 37C

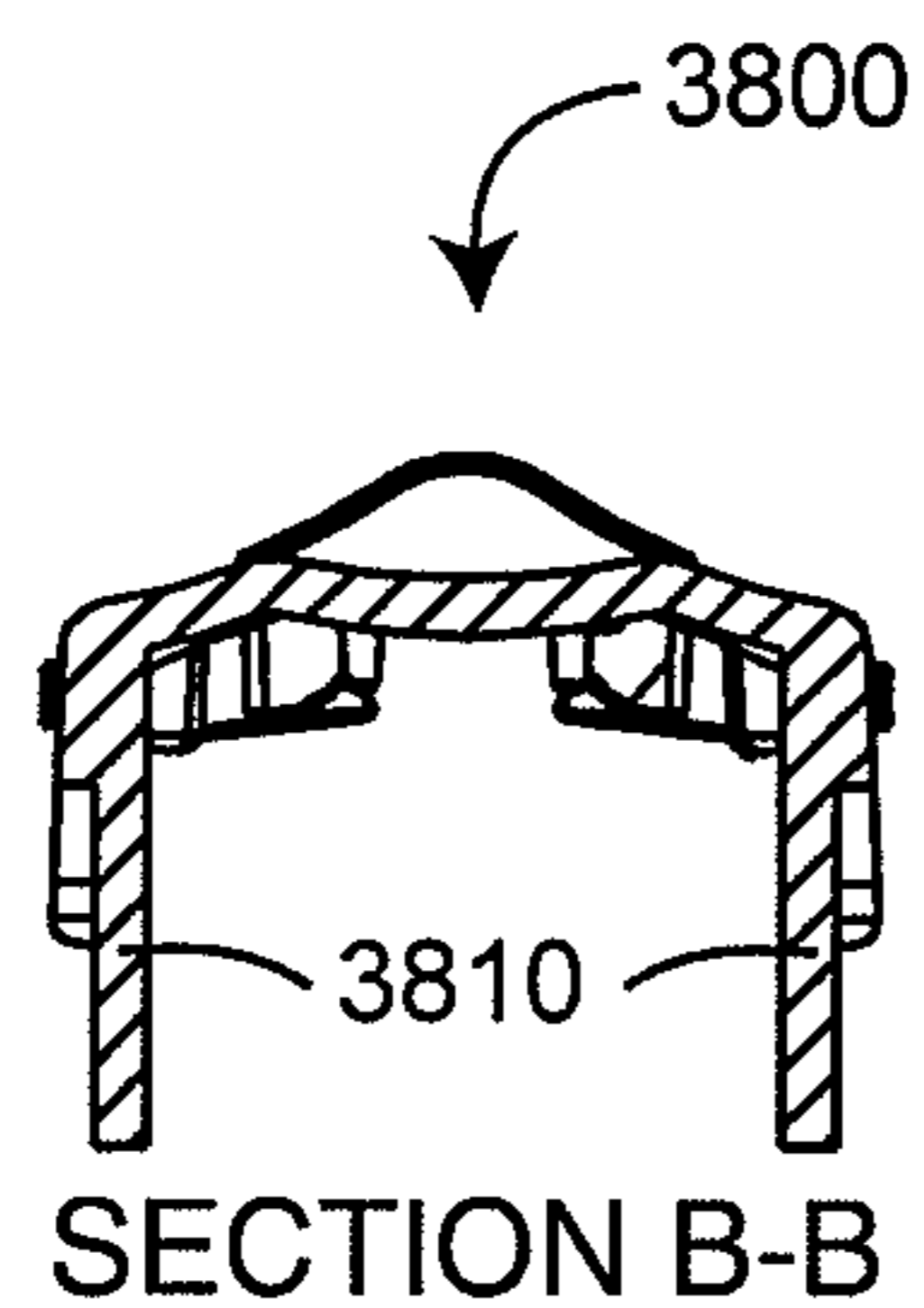


FIG. 38A

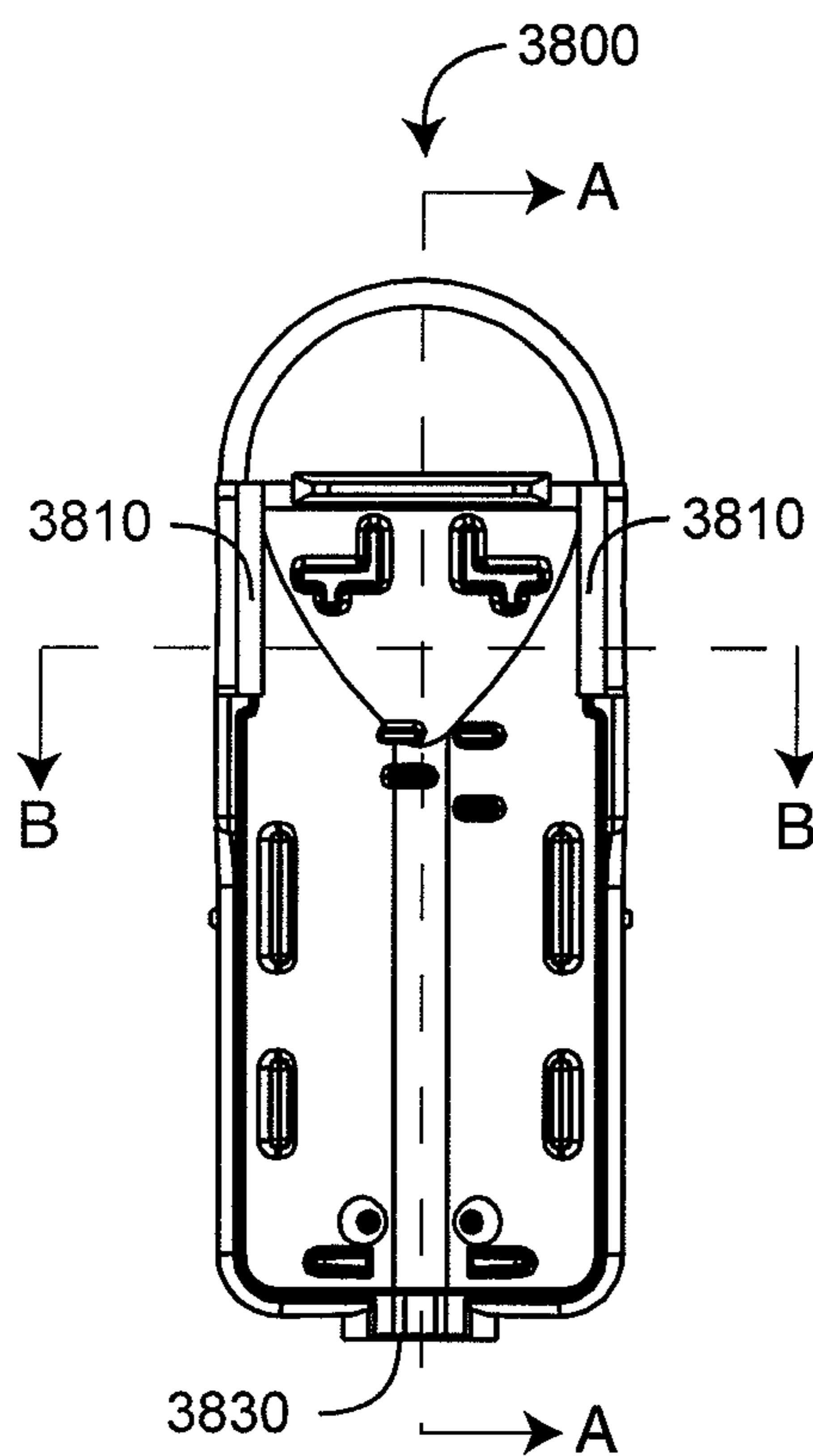
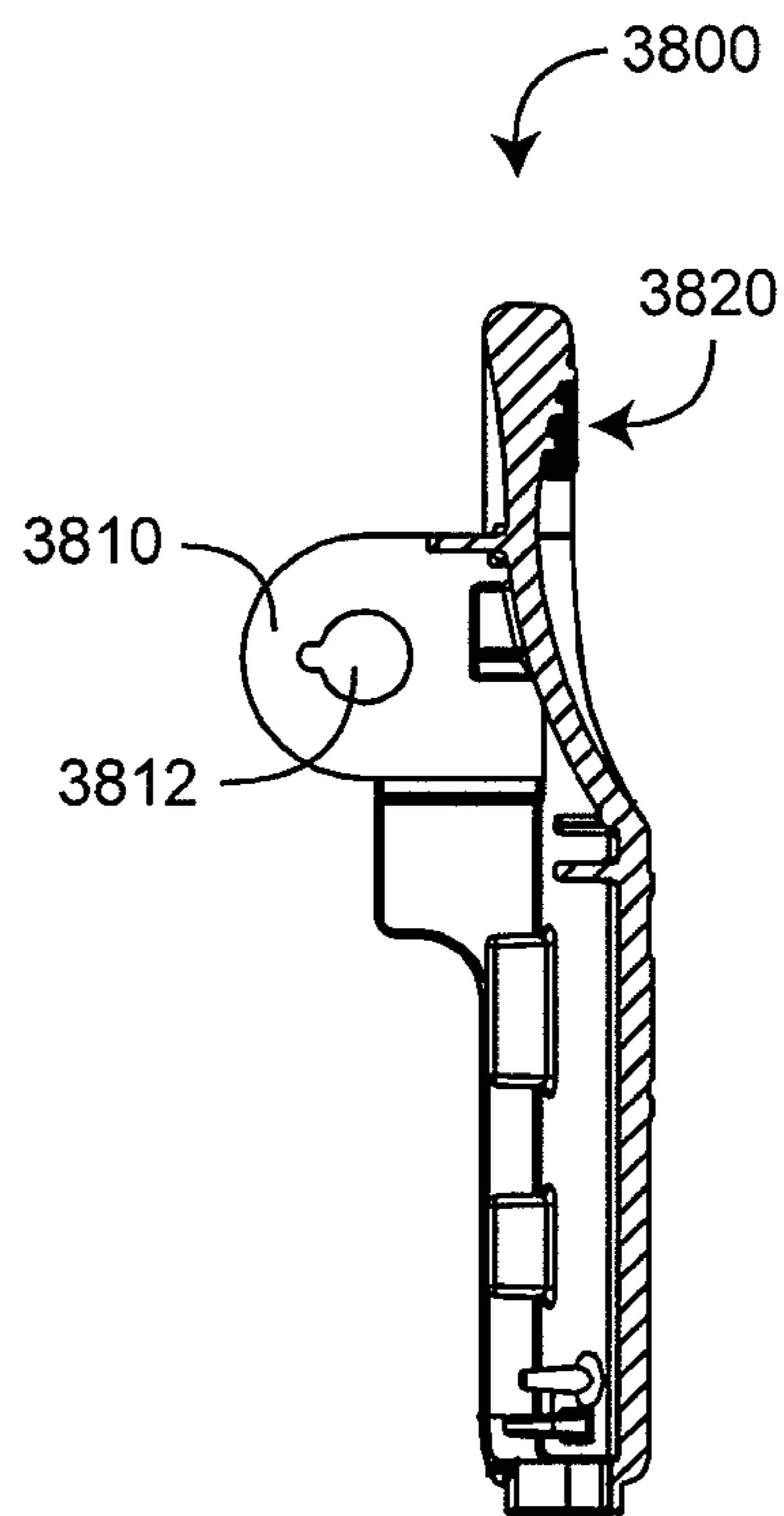


FIG. 38B



SECTION A-A
FIG. 38D

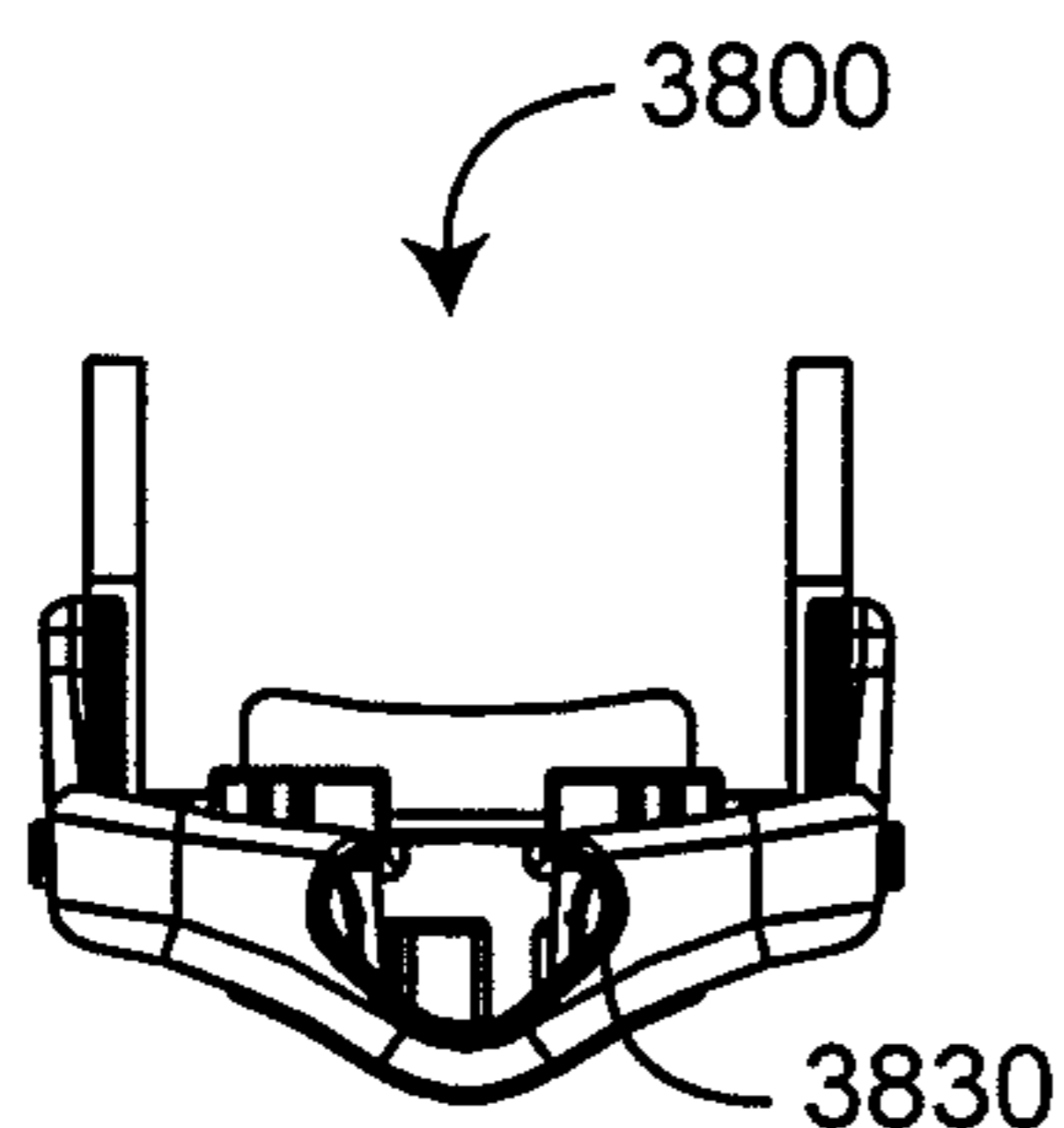


FIG. 38C

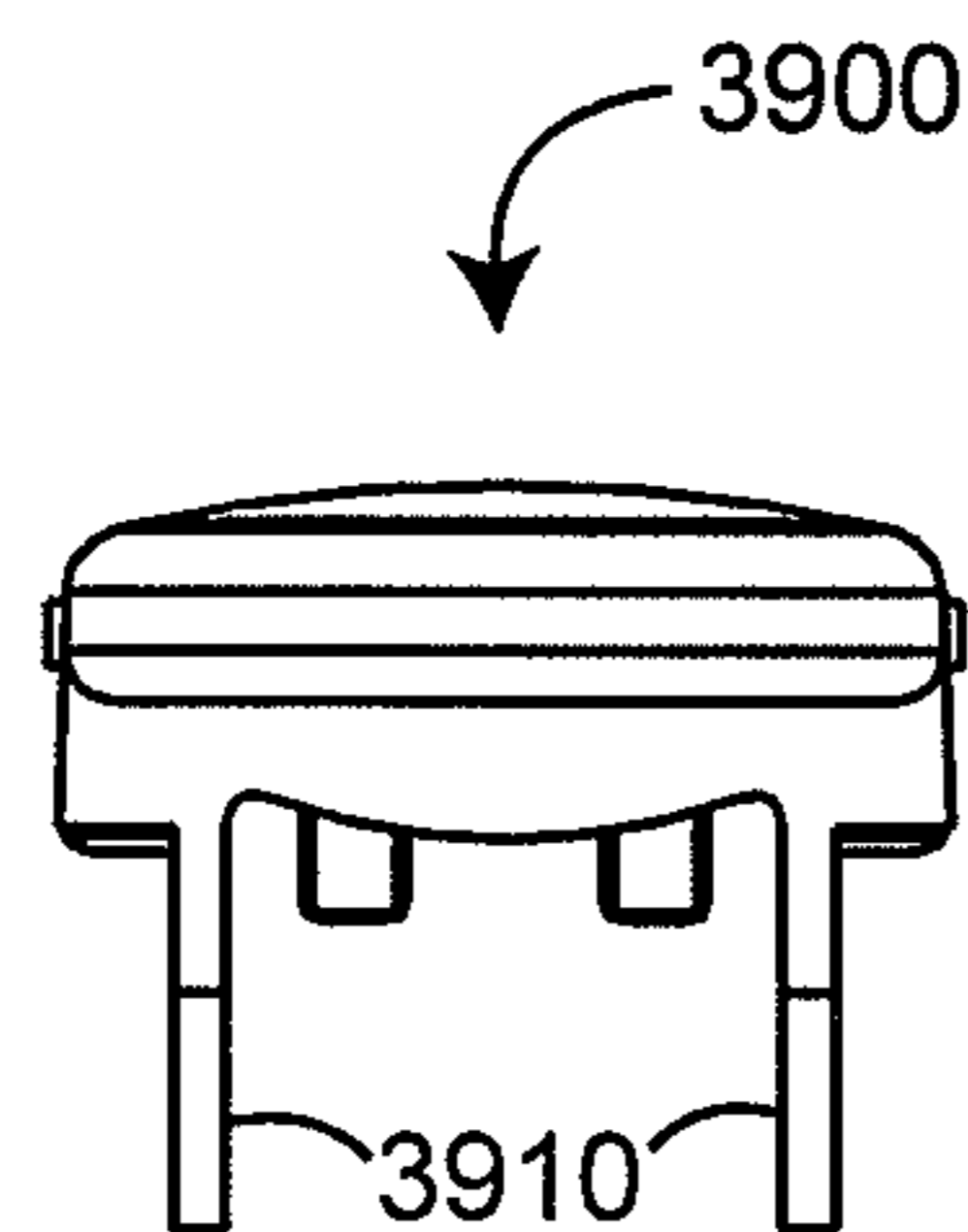


FIG. 39A

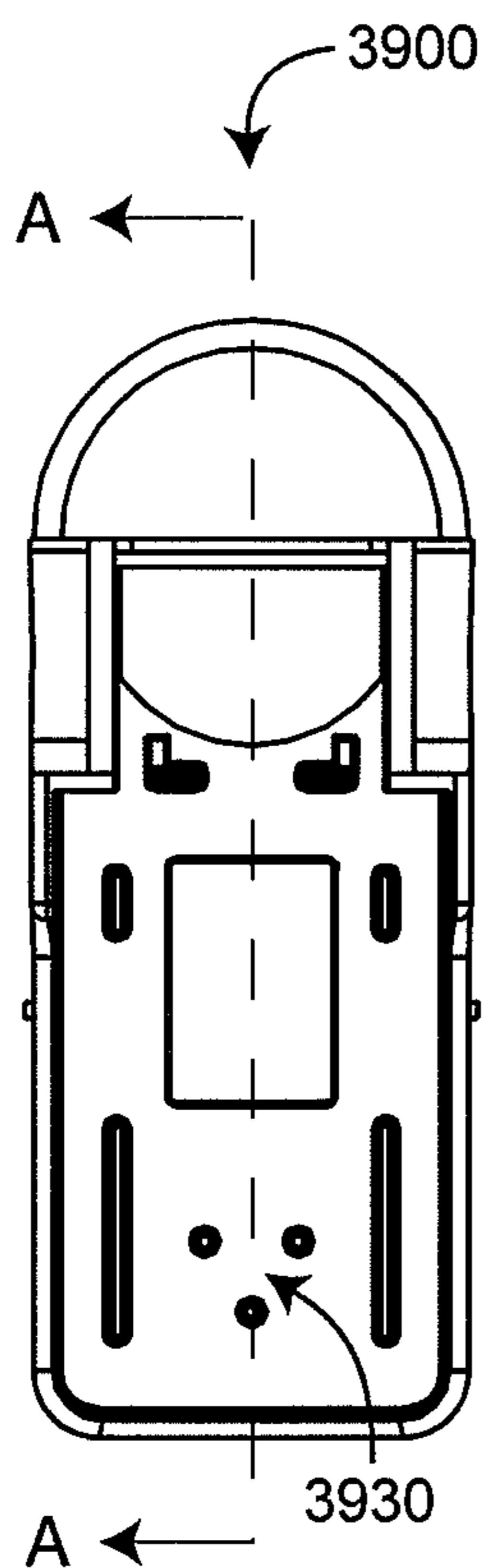


FIG. 39B

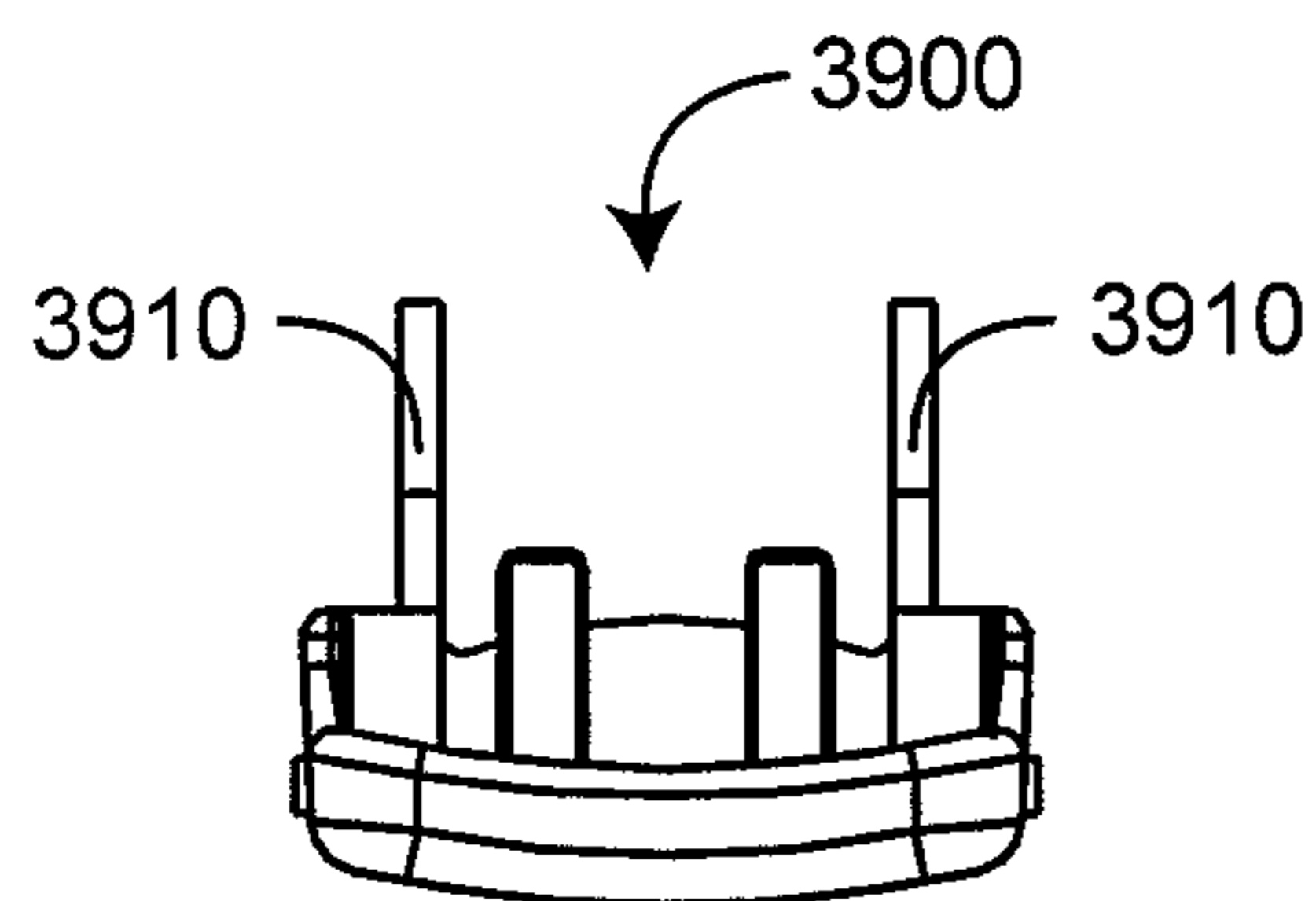
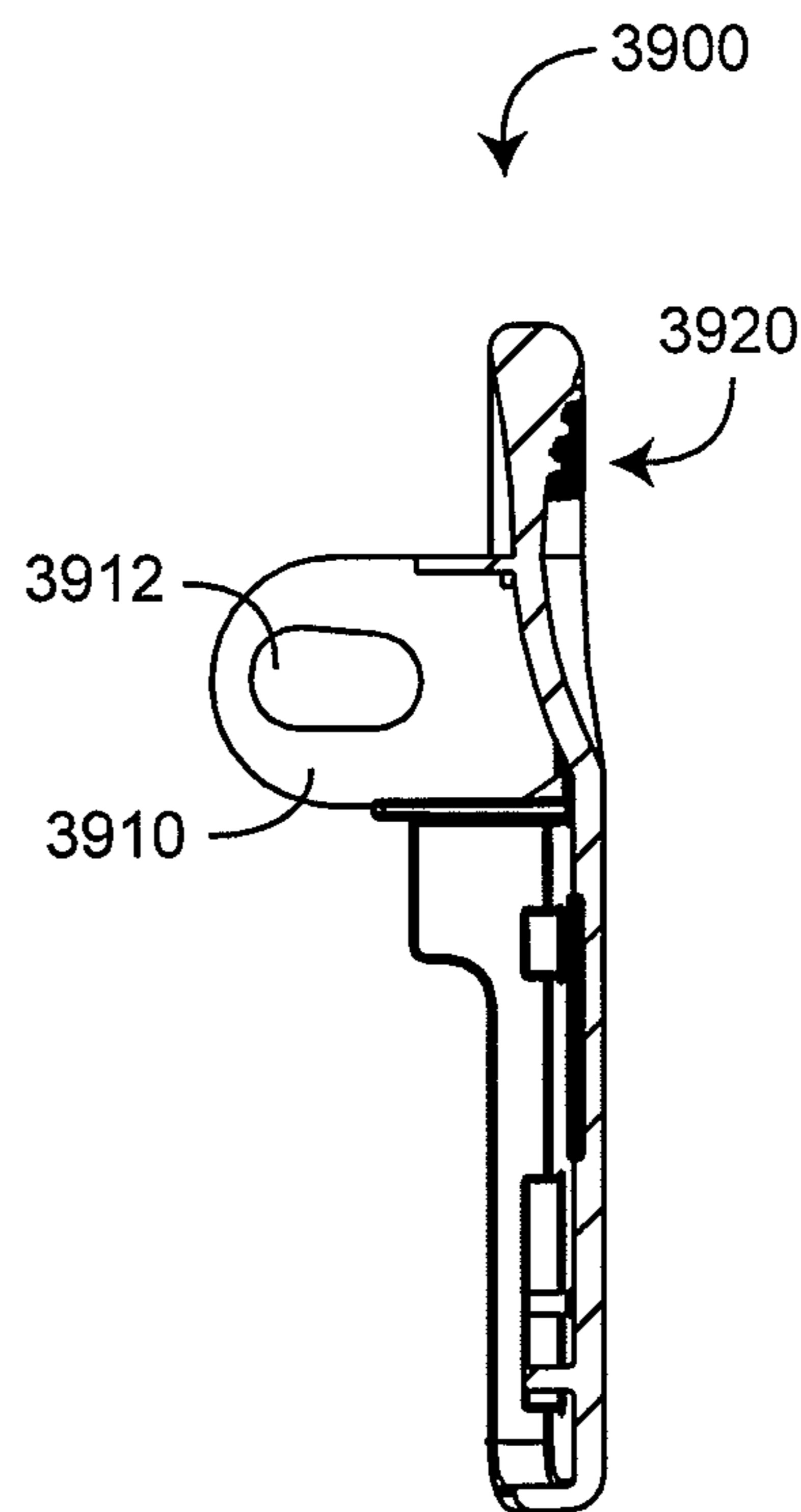


FIG. 39C



SECTION A-A
FIG. 39D

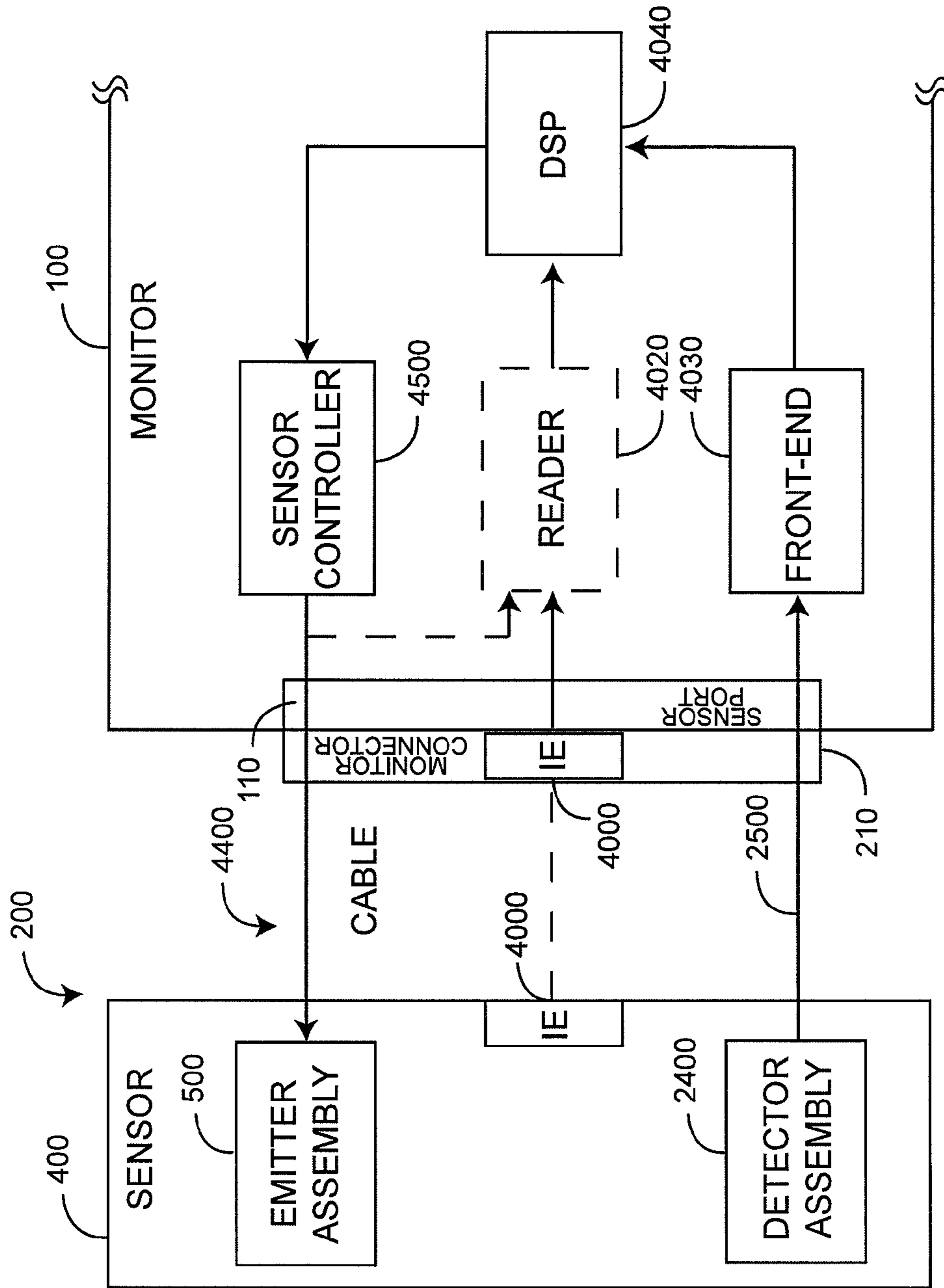


FIG. 40

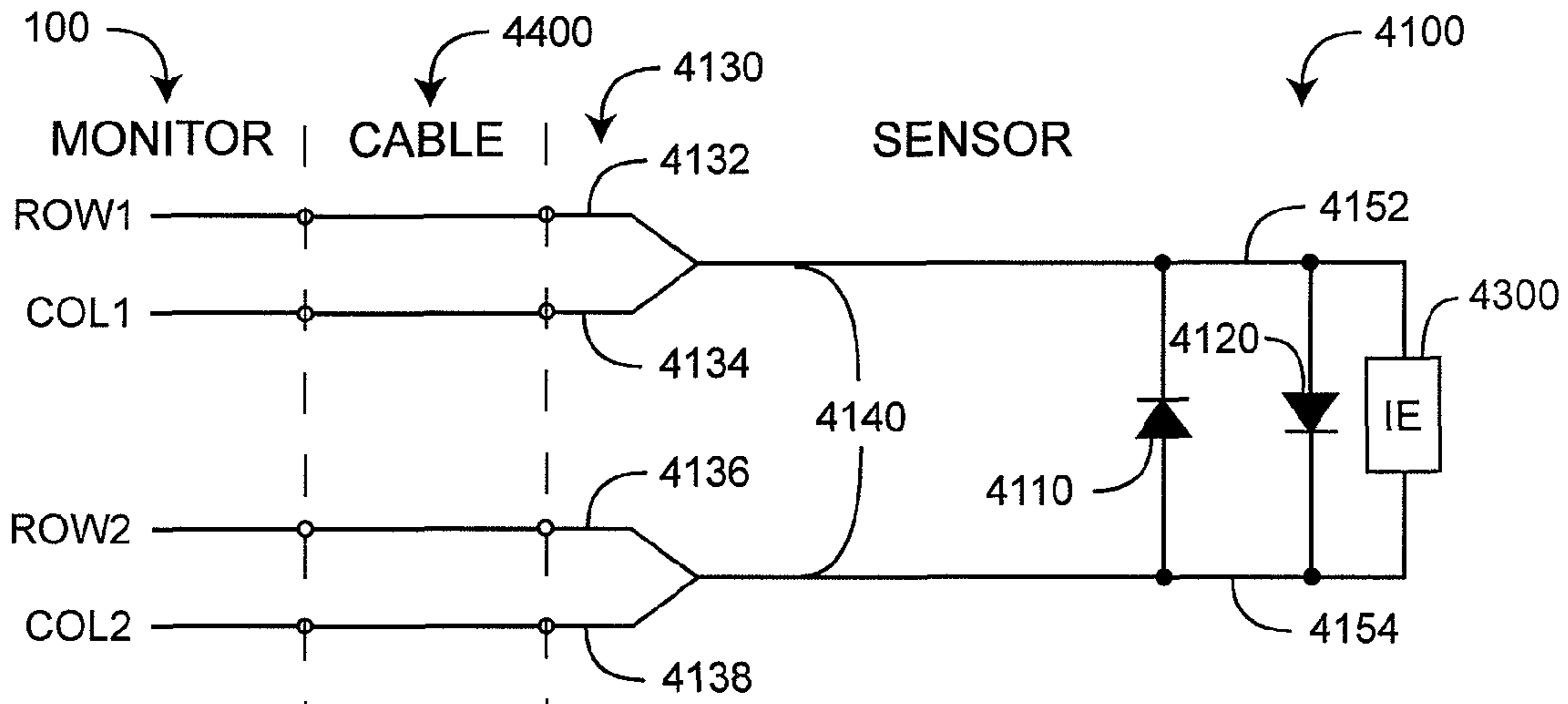


FIG. 41A

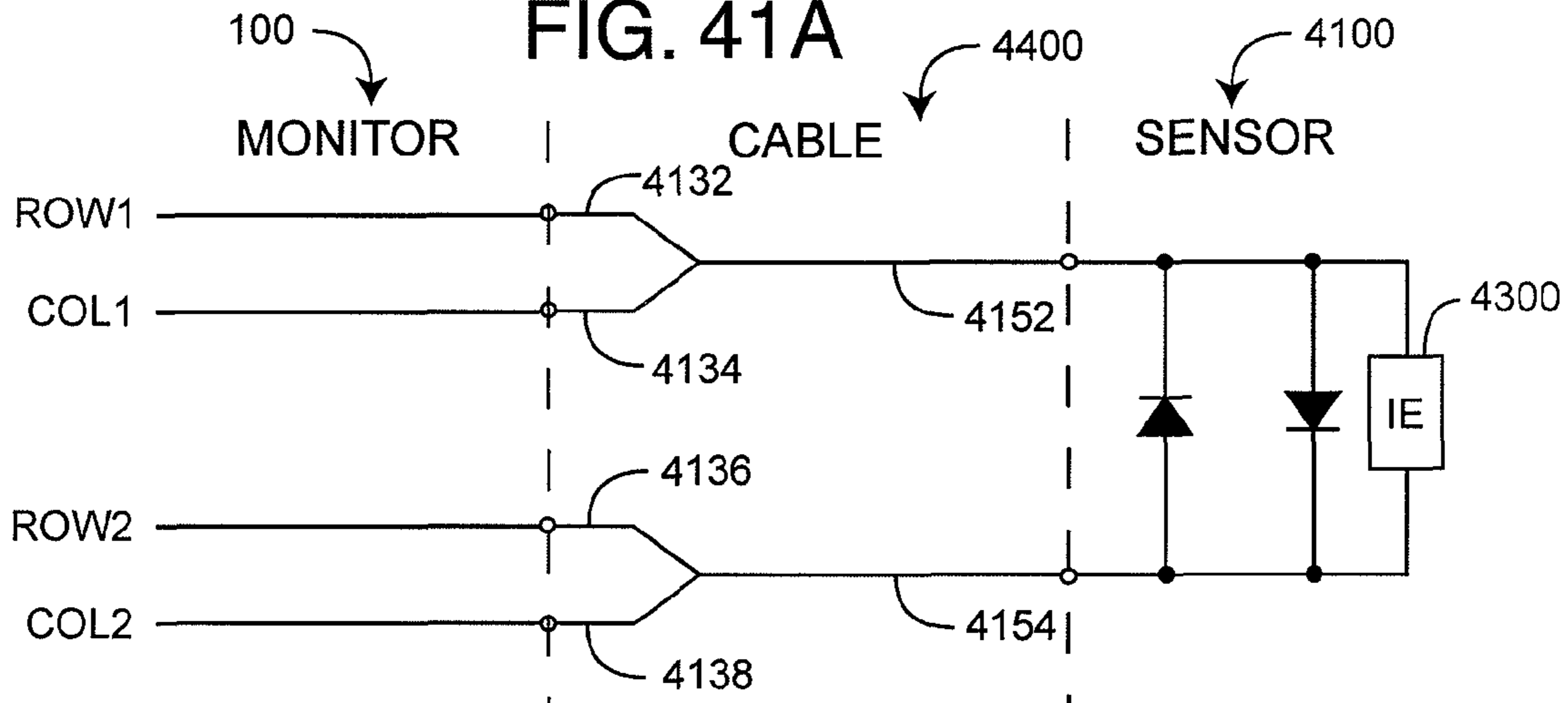


FIG. 41B

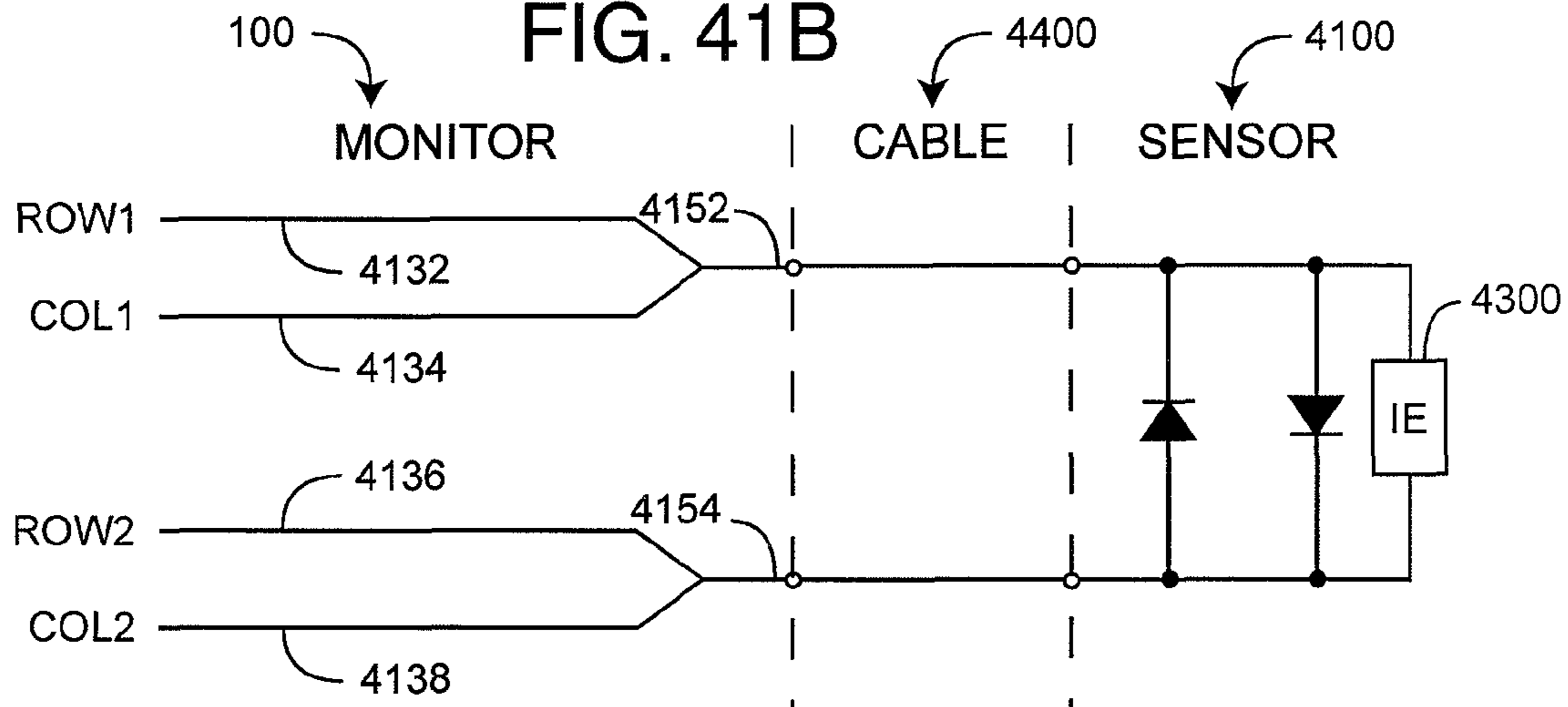


FIG. 41C

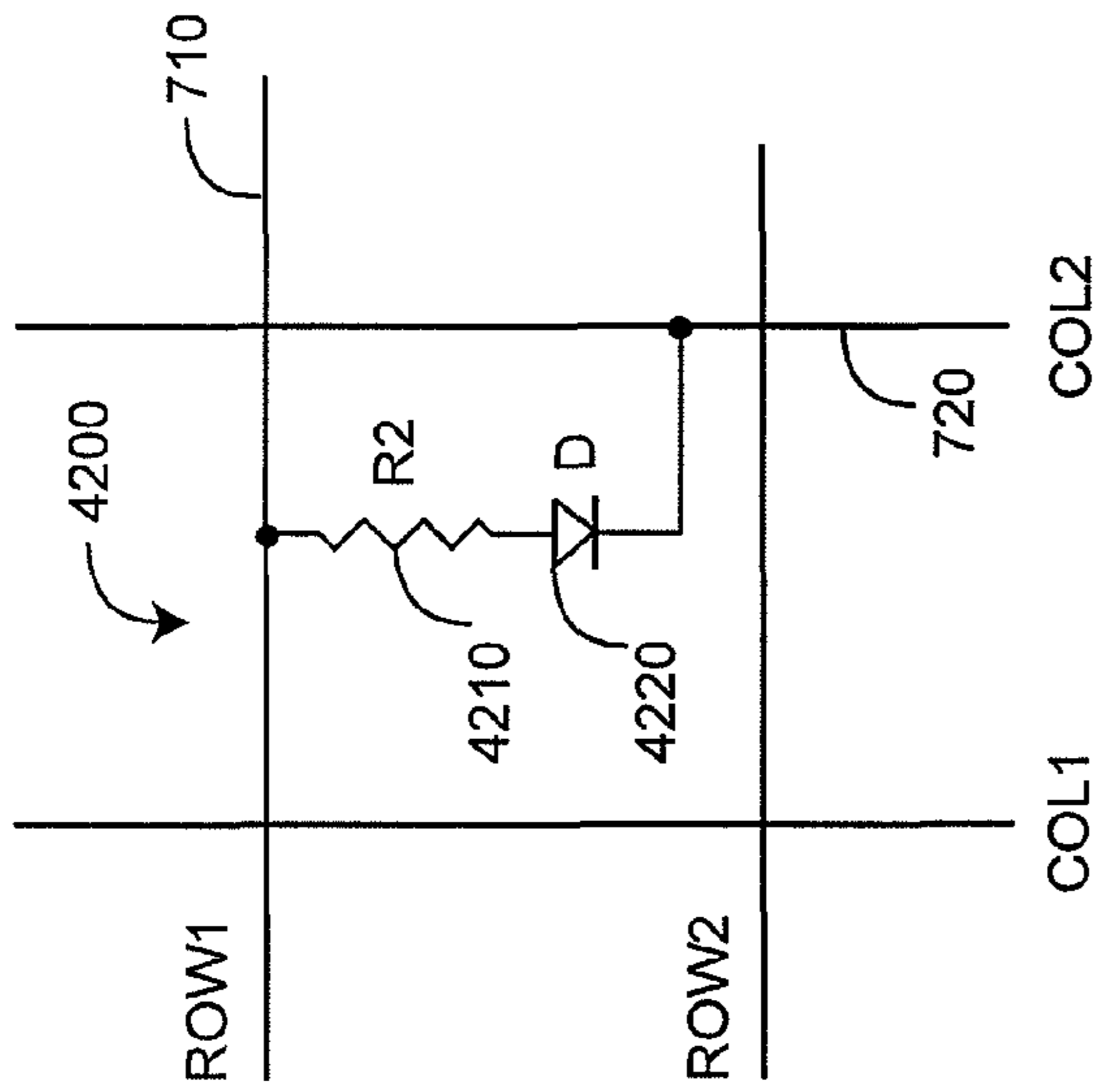


FIG. 42

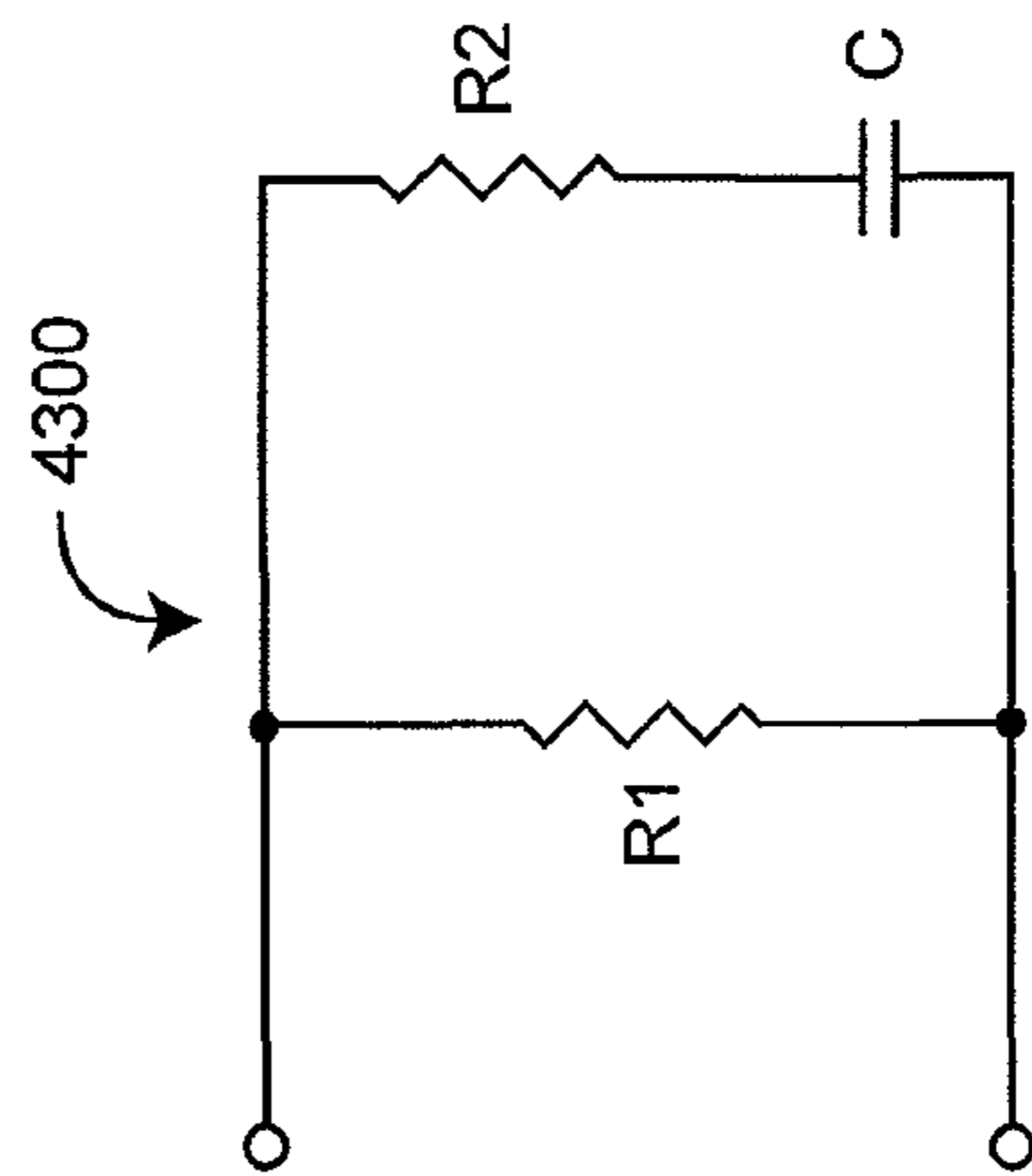


FIG. 43A

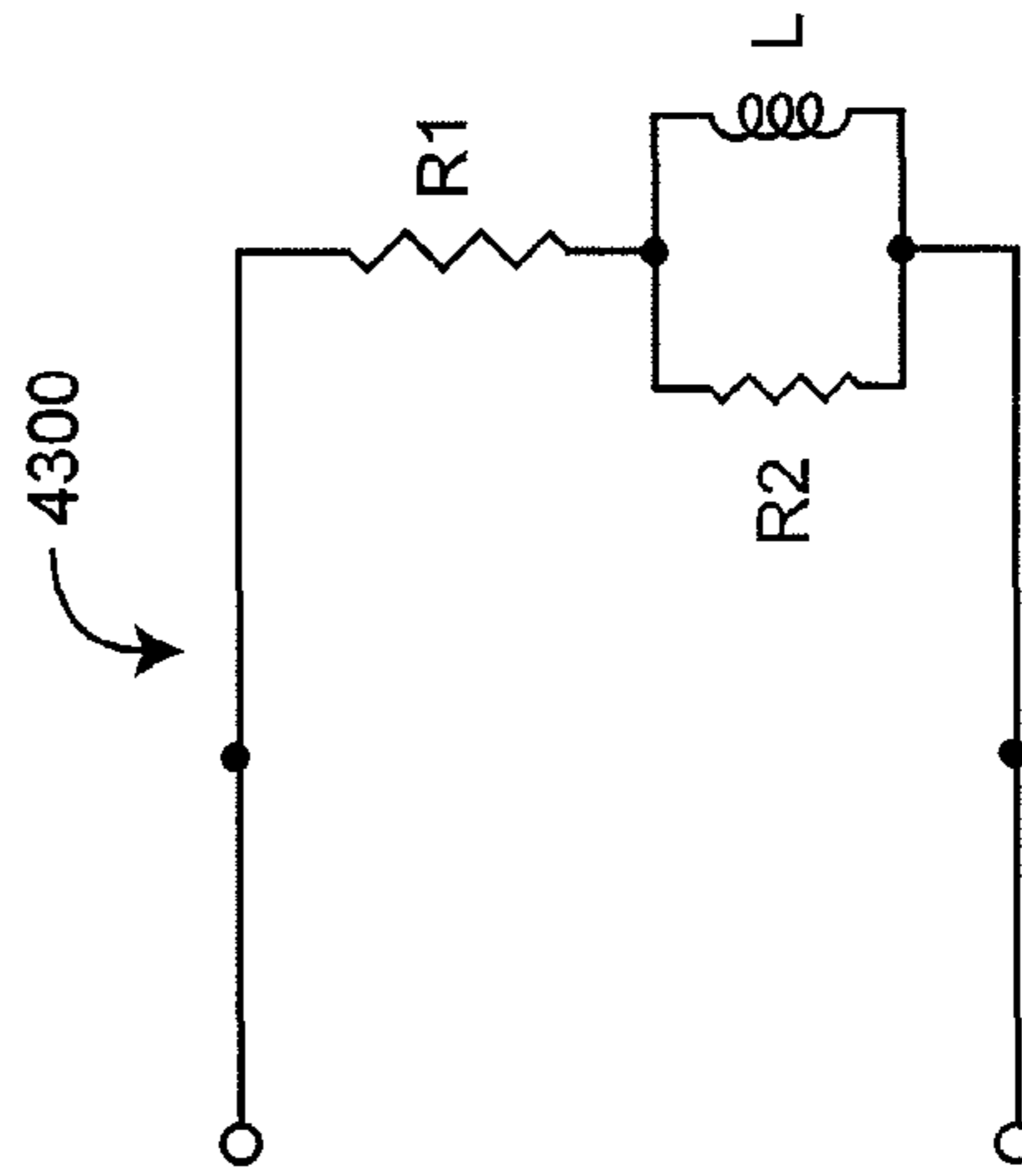


FIG. 43B

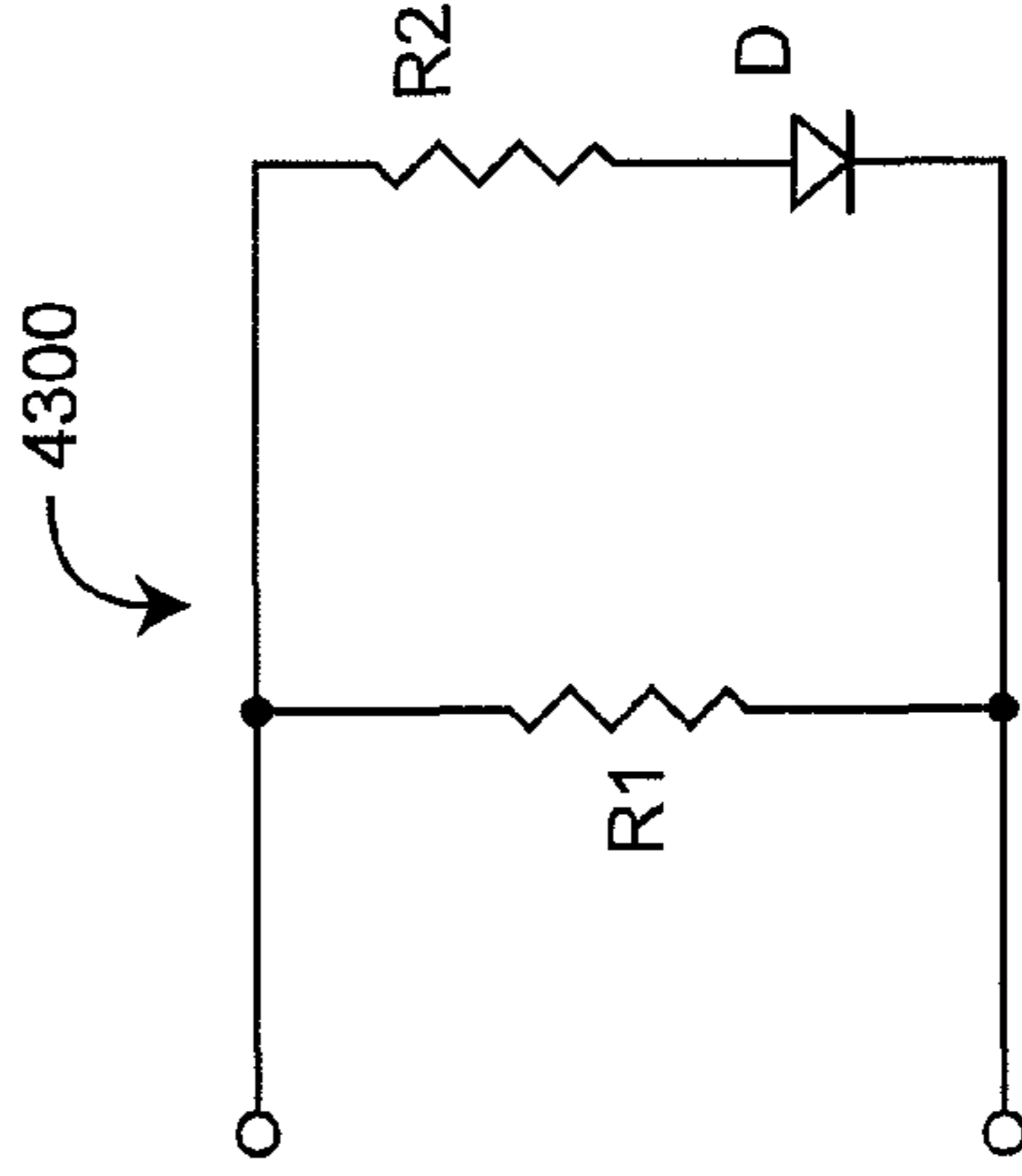


FIG. 43C

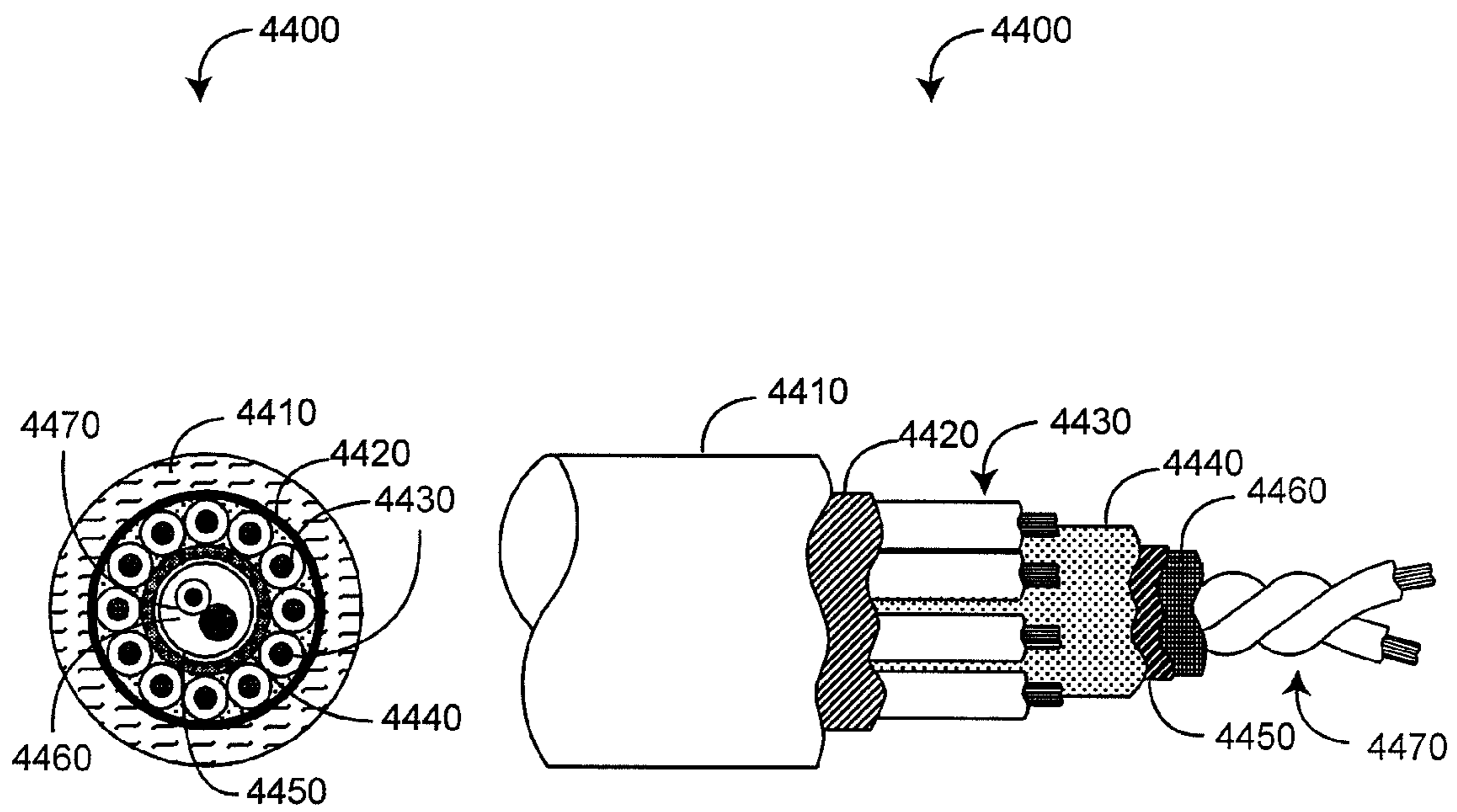


FIG. 44A

FIG. 44B

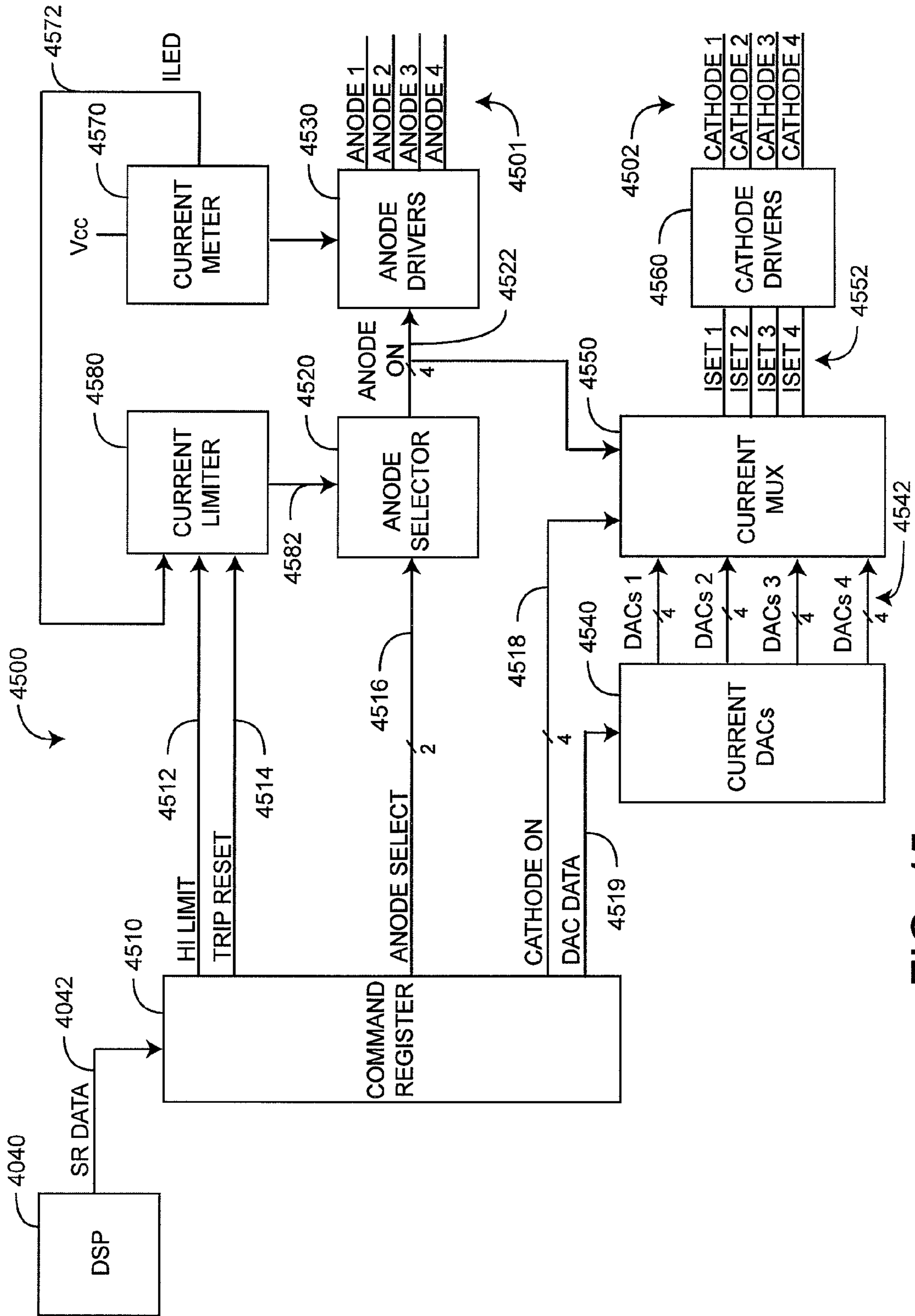


FIG. 45

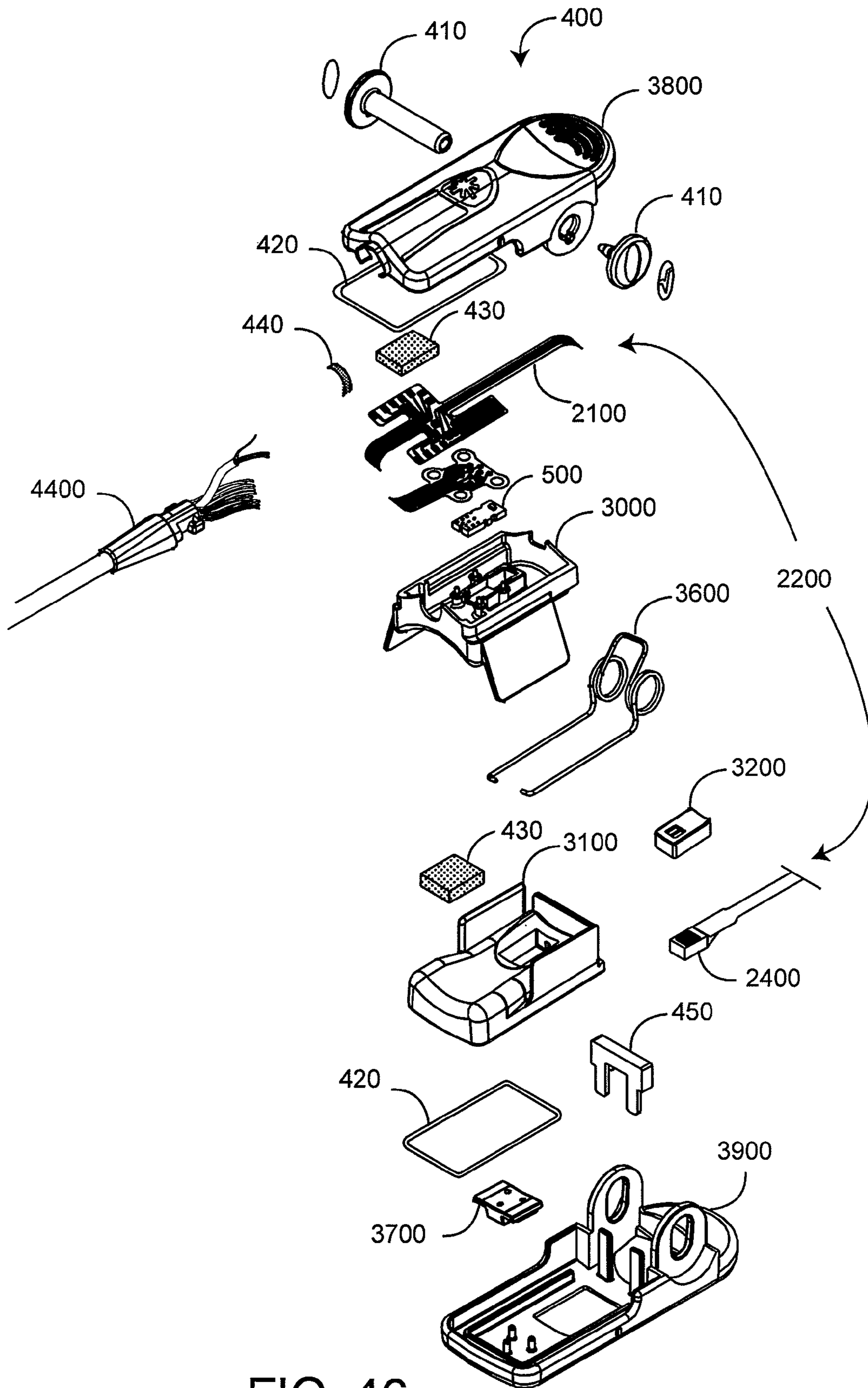


FIG. 46

1

MULTIPLE WAVELENGTH SENSOR EMITTERS

PRIORITY CLAIM

The present application is a continuation of U.S. patent application Ser. No. 13/776,065, filed Feb. 25, 2013, entitled "Multiple Wavelength Sensor Emitters," which is a continuation of U.S. patent application Ser. No. 12/422,915, filed Apr. 13, 2009, entitled "Multiple Wavelength Sensor Emitters," which is a continuation of U.S. patent application Ser. No. 11/367,013, filed Mar. 1, 2006, entitled "Multiple Wavelength Sensor Emitters," which claims priority benefit under 35 U.S.C. §119(e) to U.S. Provisional Pat. App. No. 60/657,596, filed Mar. 1, 2005, entitled "Multiple Wavelength Sensor," No. 60/657,281, filed Mar. 1, 2005, entitled "Physiological Parameter Confidence Measure," No. 60/657,268, filed Mar. 1, 2005, entitled "Configurable Physiological Measurement System," and No. 60/657,759, filed Mar. 1, 2005, entitled "Noninvasive Multi-Parameter Patient Monitor." The present application incorporates the foregoing disclosures herein by reference in their entirety.

INCORPORATION BY REFERENCE OF RELATED APPLICATIONS

The present application is related to the following U.S. utility applications:

	application Sr. No.	Filing Date	Title
1	11/367,013	Mar. 1, 2006	Multiple Wavelength Sensor Emitters
	11/546,932	Oct. 12, 2006	Disposable Wavelength Optical Sensor
2	11/366,995	Mar. 1, 2006	Multiple Wavelength Sensor Equalization
3	11/366,209	Mar. 1, 2006	Multiple Wavelength Sensor Substrate
4	11/366,210	Mar. 1, 2006	Multiple Wavelength Sensor Interconnect
5	11/366,833	Mar. 1, 2006	Multiple Wavelength Sensor Attachment
6	11/366,997	Mar. 1, 2006	Multiple Wavelength Sensor Drivers
7	11/367,034	Mar. 1, 2006	Physiological Parameter Confidence Measure
8	11/367,036	Mar. 1, 2006	Configurable Physiological Measurement System
9	11/367,033	Mar. 1, 2006	Noninvasive Multi- Parameter Patient Monitor
10	11/367,014	Mar. 1, 2006	Noninvasive Multi- Parameter Patient Monitor
11	11/366,208	Mar. 1, 2006	Noninvasive Multi- Parameter Patient Monitor
12	12/056,179	Mar. 26, 2008	Multiple Wavelength Optical Sensor
13	12/082,810	Apr. 14, 2008	Optical Sensor Assembly

The present application incorporates the foregoing disclosures herein by reference.

BACKGROUND

Spectroscopy is a common technique for measuring the concentration of organic and some inorganic constituents of a solution. The theoretical basis of this technique is the Beer-Lambert law, which states that the concentration c_i of an absorbent in solution can be determined by the intensity of light transmitted through the solution, knowing the path-

2

length d_λ , the intensity of the incident light $I_{0,\lambda}$, and the extinction coefficient $\epsilon_{i,\lambda}$ at a particular wavelength λ . In generalized form, the Beer-Lambert law is expressed as:

$$I_\lambda = I_{0,\lambda} e^{-d_\lambda \mu_{a,\lambda}} \quad (1)$$

$$\mu_{a,\lambda} = \sum_{i=1}^n \epsilon_{i,\lambda} \cdot c_i \quad (2)$$

where $\mu_{a,\lambda}$ is the bulk absorption coefficient and represents the probability of absorption per unit length. The minimum number of discrete wavelengths that are required to solve EQS. 1-2 are the number of significant absorbers that are present in the solution.

A practical application of this technique is pulse oximetry, which utilizes a noninvasive sensor to measure oxygen saturation (SpO_2) and pulse rate. In general, the sensor has light emitting diodes (LEDs) that transmit optical radiation of red and infrared wavelengths into a tissue site and a detector that responds to the intensity of the optical radiation after absorption (e.g., by transmission or transreflectance) by pulsatile arterial blood flowing within the tissue site. Based on this response, a processor determines measurements for SpO_2 , pulse rate, and can output representative plethysmographic waveforms. Thus, "pulse oximetry" as used herein encompasses its broad ordinary meaning known to one of skill in the art, which includes at least those noninvasive procedures for measuring parameters of circulating blood through spectroscopy. Moreover, "plethysmograph" as used herein (commonly referred to as "photoplethysmograph"), encompasses its broad ordinary meaning known to one of skill in the art, which includes at least data representative of a change in the absorption of particular wavelengths of light as a function of the changes in body tissue resulting from pulsing blood. Pulse oximeters capable of reading through motion induced noise are available from Masimo Corporation ("Masimo") of Irvine, Calif. Moreover, portable and other oximeters capable of reading through motion induced noise are disclosed in at least U.S. Pat. Nos. 6,770,028, 6,658,276, 6,157,850, 6,002,952, 5,769,785, and 5,758,644, which are owned by Masimo and are incorporated by reference herein. Such reading through motion oximeters have gained rapid acceptance in a wide variety of medical applications, including surgical wards, intensive care and neonatal units, general wards, home care, physical training, and virtually all types of monitoring scenarios.

SUMMARY

There is a need to noninvasively measure multiple physiological parameters, other than, or in addition to, oxygen saturation and pulse rate. For example, hemoglobin species that are also significant under certain circumstances are carboxyhemoglobin and methemoglobin. Other blood parameters that may be measured to provide important clinical information are fractional oxygen saturation, total hemaglobin (Hbt), bilirubin and blood glucose, to name a few.

One aspect of a physiological sensor is light emitting sources, each activated by addressing at least one row and at least one column of an electrical grid. The light emitting sources transmit light having multiple wavelengths and a detector is responsive to the transmitted light after attenuation by body tissue.

Another aspect of a physiological sensor is light emitting sources capable of transmitting light having multiple wavelengths. Each of the light emitting sources includes a first contact and a second contact. The first contacts of a first set of the light emitting sources are in communication with a first conductor and the second contacts of a second set of the light emitting sources are in communication with a second conductor. A detector is capable of detecting the transmitted light attenuated by body tissue and outputting a signal indicative of at least one physiological parameter of the body tissue. At least one light emitting source of the first set and at least one light emitting source of the second set are not common to the first and second sets. Further, each of the first set and the second set comprises at least two of the light emitting sources.

A further aspect of a physiological sensor sequentially addresses light emitting sources using conductors of an electrical grid so as to emit light having multiple wavelengths that when attenuated by body tissue is indicative of at least one physiological characteristic. The emitted light is detected after attenuation by body tissue.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a physiological measurement system utilizing a multiple wavelength sensor;

FIGS. 2A-C are perspective views of multiple wavelength sensor embodiments;

FIG. 3 is a general block diagram of a multiple wavelength sensor and sensor controller;

FIG. 4 is an exploded perspective view of a multiple wavelength sensor embodiment;

FIG. 5 is a general block diagram of an emitter assembly;

FIG. 6 is a perspective view of an emitter assembly embodiment;

FIG. 7 is a general block diagram of an emitter array;

FIG. 8 is a schematic diagram of an emitter array embodiment;

FIG. 9 is a general block diagram of equalization;

FIGS. 10A-D are block diagrams of various equalization embodiments;

FIGS. 11A-C are perspective views of an emitter assembly incorporating various equalization embodiments;

FIG. 12 is a general block diagram of an emitter substrate;

FIGS. 13-14 are top and detailed side views of an emitter substrate embodiment;

FIG. 15-16 are top and bottom component layout views of an emitter substrate embodiment;

FIG. 17 is a schematic diagram of an emitter substrate embodiment;

FIG. 18 is a plan view of an inner layer of an emitter substrate embodiment;

FIG. 19 is a general block diagram of an interconnect assembly in relationship to other sensor assemblies;

FIG. 20 is a block diagram of an interconnect assembly embodiment;

FIG. 21 is a partially-exploded perspective view of a flex circuit assembly embodiment of an interconnect assembly;

FIG. 22 is a top plan view of a flex circuit;

FIG. 23 is an exploded perspective view of an emitter portion of a flex circuit assembly;

FIG. 24 is an exploded perspective view of a detector assembly embodiment;

FIGS. 25-26 are block diagrams of adjacent detector and stacked detector embodiments;

FIG. 27 is a block diagram of a finger clip embodiment of an attachment assembly;

FIG. 28 is a general block diagram of a detector pad;

FIGS. 29A-B are perspective views of detector pad embodiments;

FIGS. 30A-H are perspective bottom, perspective top, bottom, back, top, side cross sectional, side, and front cross sectional views of an emitter pad embodiment;

FIGS. 31A-H are perspective bottom, perspective top, top, back, bottom, side cross sectional, side, and front cross sectional views of a detector pad embodiment;

FIGS. 32A-H are perspective bottom, perspective top, top, back, bottom, side cross sectional, side, and front cross sectional views of a shoe box;

FIGS. 33A-H are perspective bottom, perspective top, top, back, bottom, side cross sectional, side, and front cross sectional views of a slim-finger emitter pad embodiment;

FIGS. 34A-H are perspective bottom, perspective top, top, back, bottom, side cross sectional, side, and front cross sectional views of a slim-finger detector pad embodiment;

FIGS. 35A-B are plan and cross sectional views, respectively, of a spring assembly embodiment;

FIGS. 36A-C are top, perspective and side views of a finger clip spring;

FIGS. 37A-D are top, back, bottom, and side views of a spring plate;

FIGS. 38A-D are front cross sectional, bottom, front and side cross sectional views of an emitter-pad shell;

FIGS. 39A-D are back, top, front and side cross sectional views of a detector-pad shell;

FIG. 40 is a general block diagram of a monitor and a sensor;

FIGS. 41A-C are schematic diagrams of grid drive embodiments for a sensor having back-to-back diodes and an information element;

FIG. 42 is a schematic diagrams of a grid drive embodiment for an information element;

FIGS. 43A-C are schematic diagrams for grid drive readable information elements;

FIGS. 44A-B are cross sectional and side cut away views of a sensor cable;

FIG. 45 is a block diagram of a sensor controller embodiment; and

FIG. 46 is a detailed exploded perspective view of a multiple wavelength sensor embodiment.

DETAILED DESCRIPTION

Overview

In this application, reference is made to many blood parameters. Some references that have common shorthand designations are referenced through such shorthand designations. For example, as used herein, HbCO designates carboxyhemoglobin, HbMet designates methemoglobin, and Hbt designates total hemoglobin. Other shorthand designations such as COHb, MetHb, and tHb are also common in the art for these same constituents. These constituents are generally reported in terms of a percentage, often referred to as saturation, relative concentration or fractional saturation. Total hemoglobin is generally reported as a concentration in g/dL. The use of the particular shorthand designators presented in this application does not restrict the term to any particular manner in which the designated constituent is reported.

FIG. 1 illustrates a physiological measurement system 10 having a monitor 100 and a multiple wavelength sensor assembly 200 with enhanced measurement capabilities as compared with conventional pulse oximetry. The physiological measurement system 10 allows the monitoring of a

person, including a patient. In particular, the multiple wavelength sensor assembly **200** allows the measurement of blood constituent and related parameters in addition to oxygen saturation and pulse rate. Alternatively, the multiple wavelength sensor assembly **200** allows the measurement of oxygen saturation and pulse rate with increased accuracy or robustness as compared with conventional pulse oximetry.

In one embodiment, the sensor assembly **200** is configured to plug into a monitor sensor port **110**. Monitor keys **160** provide control over operating modes and alarms, to name a few. A display **170** provides readouts of measured parameters, such as oxygen saturation, pulse rate, HbCO and HbMet to name a few.

FIG. 2A illustrates a multiple wavelength sensor assembly **200** having a sensor **400** adapted to attach to a tissue site, a sensor cable **4400** and a monitor connector **210**. In one embodiment, the sensor **400** is incorporated into a reusable finger clip adapted to removably attach to, and transmit light through, a fingertip. The sensor cable **4400** and monitor connector **210** are integral to the sensor **400**, as shown. In alternative embodiments, the sensor **400** may be configured separately from the cable **4400** and connector **210**.

FIGS. 2B-C illustrate alternative sensor embodiments, including a sensor **401** (FIG. 2B) partially disposable and partially reusable (resposable) and utilizing an adhesive attachment mechanism. Also shown is a sensor **402** (FIG. 2C) being disposable and utilizing an adhesive attachment mechanism. In other embodiments, a sensor may be configured to attach to various tissue sites other than a finger, such as a foot or an ear. Also a sensor may be configured as a reflectance or transreflectance device that attaches to a forehead or other tissue surface.

FIG. 3 illustrates a sensor assembly **400** having an emitter assembly **500**, a detector assembly **2400**, an interconnect assembly **1900** and an attachment assembly **2700**. The emitter assembly **500** responds to drive signals received from a sensor controller **4500** in the monitor **100** via the cable **4400** so as to transmit optical radiation having a plurality of wavelengths into a tissue site. The detector assembly **2400** provides a sensor signal to the monitor **100** via the cable **4400** in response to optical radiation received after attenuation by the tissue site. The interconnect assembly **1900** provides electrical communication between the cable **4400** and both the emitter assembly **500** and the detector assembly **2400**. The attachment assembly **2700** attaches the emitter assembly **500** and detector assembly **2400** to a tissue site, as described above. The emitter assembly **500** is described in further detail with respect to FIG. 5, below. The interconnect assembly **1900** is described in further detail with respect to FIG. 19, below. The detector assembly **2400** is described in further detail with respect to FIG. 24, below. The attachment assembly **2700** is described in further detail with respect to FIG. 27, below.

FIG. 4 illustrates a sensor **400** embodiment that removably attaches to a fingertip. The sensor **400** houses a multiple wavelength emitter assembly **500** and corresponding detector assembly **2400**. A flex circuit assembly **1900** mounts the emitter and detector assemblies **500**, **2400** and interconnects them to a multi-wire sensor cable **4400**. Advantageously, the sensor **400** is configured in several respects for both wearer comfort and parameter measurement performance. The flex circuit assembly **1900** is configured to mechanically decouple the cable **4400** wires from the emitter and detector assemblies **500**, **2400** to reduce pad stiffness and wearer discomfort. The pads **3000**, **3100** are mechanically decoupled from shells **3800**, **3900** to increase flexibility and wearer comfort. A spring **3600** is configured in hinged shells

3800, **3900** so that the pivot point of the finger clip is well behind the fingertip, improving finger attachment and more evenly distributing the clip pressure along the finger.

As shown in FIG. 4, the detector pad **3100** is structured to properly position a fingertip in relationship to the detector assembly **2400**. The pads have flaps that block ambient light. The detector assembly **2400** is housed in an enclosure so as to reduce light piping from the emitter assembly to the detector assembly without passing through fingertip tissue. These and other features are described in detail below. Specifically, emitter assembly embodiments are described with respect to FIGS. 5-18. Interconnect assembly embodiments, including the flexible circuit assembly **1900**, are described with respect to FIGS. 19-23. Detector assembly embodiments are described with respect to FIGS. 24-26. Attachment assembly embodiments are described with respect to FIGS. 27-39.

Emitter Assembly

FIG. 5 illustrates an emitter assembly **500** having an emitter array **700**, a substrate **1200** and equalization **900**. The emitter array **700** has multiple light emitting sources, each activated by addressing at least one row and at least one column of an electrical grid. The light emitting sources are capable of transmitting optical radiation having multiple wavelengths. The equalization **900** accounts for differences in tissue attenuation of the optical radiation across the multiple wavelengths so as to at least reduce wavelength-dependent variations in detected intensity. The substrate **1200** provides a physical mount for the emitter array and emitter-related equalization and a connection between the emitter array and the interconnection assembly. Advantageously, the substrate **1200** also provides a bulk temperature measurement so as to calculate the operating wavelengths for the light emitting sources. The emitter array **700** is described in further detail with respect to FIG. 7, below. Equalization is described in further detail with respect to FIG. 9, below. The substrate **1200** is described in further detail with respect to FIG. 12, below.

FIG. 6 illustrates an emitter assembly **500** embodiment having an emitter array **700**, an encapsulant **600**, an optical filter **1100** and a substrate **1200**. Various aspects of the emitter assembly **500** are described with respect to FIGS. 7-18, below. The emitter array **700** emits optical radiation having multiple wavelengths of predetermined nominal values, advantageously allowing multiple parameter measurements. In particular, the emitter array **700** has multiple light emitting diodes (LEDs) **710** that are physically arranged and electrically connected in an electrical grid to facilitate drive control, equalization, and minimization of optical pathlength differences at particular wavelengths. The optical filter **1100** is advantageously configured to provide intensity equalization across a specific LED subset. The substrate **1200** is configured to provide a bulk temperature of the emitter array **700** so as to better determine LED operating wavelengths.

Emitter Array

FIG. 7 illustrates an emitter array **700** having multiple light emitters (LE) **710** capable of emitting light **702** having multiple wavelengths into a tissue site **1**. Row drivers **4530** and column drivers **4560** are electrically connected to the light emitters **710** and activate one or more light emitters **710** by addressing at least one row **720** and at least one column **740** of an electrical grid. In one embodiment, the light emitters **710** each include a first contact **712** and a second contact **714**. The first contact **712** of a first subset **730** of light emitters is in communication with a first conductor **720** of the electrical grid. The second contact **714** of a second subset **750** of light emitters is in communication with a

second conductor **740**. Each subset comprises at least two light emitters, and at least one of the light emitters of the first and second subsets **730**, **750** are not in common. A detector **2400** is capable of detecting the emitted light **702** and outputting a sensor signal **2500** responsive to the emitted light **702** after attenuation by the tissue site **1**. As such, the sensor signal **2500** is indicative of at least one physiological parameter corresponding to the tissue site **1**, as described above.

FIG. **8** illustrates an emitter array **700** having LEDs **801** connected within an electrical grid of n rows and m columns totaling $n+m$ drive lines **4501**, **4502**, where n and m integers greater than one. The electrical grid advantageously minimizes the number of drive lines required to activate the LEDs **801** while preserving flexibility to selectively activate individual LEDs **801** in any sequence and multiple LEDs **801** simultaneously. The electrical grid also facilitates setting LED currents so as to control intensity at each wavelength, determining operating wavelengths and monitoring total grid current so as to limit power dissipation. The emitter array **700** is also physically configured in rows **810**. This physical organization facilitates clustering LEDs **801** according to wavelength so as to minimize pathlength variations and facilitates equalization of LED intensities.

As shown in FIG. **8**, one embodiment of an emitter array **700** comprises up to sixteen LEDs **801** configured in an electrical grid of four rows **810** and four columns **820**. Each of the four row drive lines **4501** provide a common anode connection to four LEDs **801**, and each of the four column drive lines **4502** provide a common cathode connection to four LEDs **801**. Thus, the sixteen LEDs **801** are advantageously driven with only eight wires, including four anode drive lines **812** and four cathode drive lines **822**. This compares favorably to conventional common anode or cathode LED configurations, which require more drive lines. In a particular embodiment, the emitter array **700** is partially populated with eight LEDs having nominal wavelengths as shown in TABLE 1. Further, LEDs having wavelengths in the range of 610-630 nm are grouped together in the same row. The emitter array **700** is adapted to a physiological measurement system **10** (FIG. **1**) for measuring H_bCO and/or $METHb$ in addition to S_pO_2 and pulse rate.

TABLE 1

Nominal LED Wavelengths			
LED	λ	Row	Col
D1	630	1	1
D2	620	1	2
D3	610	1	3
D4		1	4
D5	700	2	1
D6	730	2	2
D7	660	2	3
D8	805	2	4
D9		3	1
D10		3	2
D11		3	3
D12	905	3	4
D13		4	1
D14		4	2
D15		4	3
D16		4	4

Also shown in FIG. **8**, row drivers **4530** and column drivers **4560** located in the monitor **100** selectively activate the LEDs **801**. In particular, row and column drivers **4530**, **4560** function together as switches to V_{cc} and current sinks,

respectively, to activate LEDs and as switches to ground and V_{cc} , respectively, to deactivate LEDs. This push-pull drive configuration advantageously prevents parasitic current flow in deactivated LEDs. In a particular embodiment, only one row drive line **4501** is switched to V_{cc} at a time. One to four column drive lines **4502**, however, can be simultaneously switched to a current sink so as to simultaneously activate multiple LEDs within a particular row. Activation of two or more LEDs of the same wavelength facilitates intensity equalization, as described with respect to FIGS. **9-11**, below. LED drivers are described in further detail with respect to FIG. **45**, below.

Although an emitter assembly is described above with respect to an array of light emitters each configured to transmit optical radiation centered around a nominal wavelength, in another embodiment, an emitter assembly advantageously utilizes one or more tunable broadband light sources, including the use of filters to select the wavelength, so as to minimize wavelength-dependent pathlength differences from emitter to detector. In yet another emitter assembly embodiment, optical radiation from multiple emitters each configured to transmit optical radiation centered around a nominal wavelength is funneled to a tissue site point so as to minimize wavelength-dependent pathlength differences. This funneling may be accomplished with fiber optics or mirrors, for example. In further embodiments, the LEDs **801** can be configured with alternative orientations with correspondingly different drivers among various other configurations of LEDs, drivers and interconnecting conductors.

Equalization

FIG. **9** illustrate a physiological parameter measurement system **10** having a controller **4500**, an emitter assembly **500**, a detector assembly **2400** and a front-end **4030**. The emitter assembly **500** is configured to transmit optical radiation having multiple wavelengths into the tissue site **1**. The detector assembly **2400** is configured to generate a sensor signal **2500** responsive to the optical radiation after tissue attenuation. The front-end **4030** conditions the sensor signal **2500** prior to analog-to-digital conversion (ADC).

FIG. **9** also generally illustrates equalization **900** in a physiological measurement system **10** operating on a tissue site **1**. Equalization encompasses features incorporated into the system **10** in order to provide a sensor signal **2500** that falls well within the dynamic range of the ADC across the entire spectrum of emitter wavelengths. In particular, equalization compensates for the imbalance in tissue light absorption due to Hb and HbO_2 **910**. Specifically, these blood constituents attenuate red wavelengths greater than IR wavelengths. Ideally, equalization **900** balances this unequal attenuation. Equalization **900** can be introduced anywhere in the system **10** from the controller **4500** to front-end **4000** and can include compensatory attenuation versus wavelength, as shown, or compensatory amplification versus or both.

Equalization can be achieved to a limited extent by adjusting drive currents from the controller **4500** and front-end **4030** amplification accordingly to wavelength so as to compensate for tissue absorption characteristics. Signal demodulation constraints, however, limit the magnitude of these adjustments. Advantageously, equalization **900** is also provided along the optical path from emitters **500** to detector **2400**. Equalization embodiments are described in further detail with respect to FIGS. **10-11**, below.

FIGS. **10A-D** illustrate various equalization embodiments having an emitter array **700** adapted to transmit optical radiation into a tissue site **1** and a detector assembly **2400** adapted to generate a sensor signal **2500** responsive to the optical radiation after tissue attenuation. FIG. **10A** illustrates

an optical filter **1100** that attenuates at least a portion of the optical radiation before it is transmitted into a tissue site **1**. In particular, the optical filter **1100** attenuates at least a portion of the IR wavelength spectrum of the optical radiation so as to approximate an equalization curve **900** (FIG. **9**). FIG. **10B** illustrates an optical filter **1100** that attenuates at least a portion of the optical radiation after it is attenuated by a tissue site **1**, where the optical filter **1100** approximates an equalization curve **900** (FIG. **9**).

FIG. **10C** illustrates an emitter array **700** where at least a portion of the emitter array generates one or more wavelengths from multiple light emitters **710** of the same wavelength. In particular, the same-wavelength light emitters **710** boost at least a portion of the red wavelength spectrum so as to approximately equalize the attenuation curves **910** (FIG. **9**). FIG. **10D** illustrates a detector assembly **2400** having multiple detectors **2610**, **2620** selected so as to equalize the attenuation curves **910** (FIG. **9**). To a limited extent, optical equalization can also be achieved by selection of particular emitter array **700** and detector **2400** components, e.g. LEDs having higher output intensities or detectors having higher sensitivities at red wavelengths. Although equalization embodiments are described above with respect to red and IR wavelengths, these equalization embodiments can be applied to equalize tissue characteristics across any portion of the optical spectrum.

FIGS. **11A-C** illustrates an optical filter **1100** for an emitter assembly **500** that advantageously provides optical equalization, as described above. LEDs within the emitter array **700** may be grouped according to output intensity or wavelength or both. Such a grouping facilitates equalization of LED intensity across the array. In particular, relatively low tissue absorption and/or relatively high output intensity LEDs can be grouped together under a relatively high attenuation optical filter. Likewise, relatively low tissue absorption and/or relatively low output intensity LEDs can be grouped together without an optical filter or under a relatively low or negligible attenuation optical filter. Further, high tissue absorption and/or low intensity LEDs can be grouped within the same row with one or more LEDs of the same wavelength being simultaneously activated, as described with respect to FIG. **10C**, above. In general, there can be any number of LED groups and any number of LEDs within a group. There can also be any number of optical filters corresponding to the groups having a range of attenuation, including no optical filter and/or a “clear” filter having negligible attenuation.

As shown in FIGS. **11A-C**, a filtering media may be advantageously added to an encapsulant that functions both as a cover to protect LEDs and bonding wires and as an optical filter **1100**. In one embodiment, a filtering media **1100** encapsulates a select group of LEDs and a clear media **600** (FIG. **6**) encapsulates the entire array **700** and the filtering media **1000** (FIG. **6**). In a particular embodiment, corresponding to TABLE 1, above, five LEDs nominally emitting at 660-905 nm are encapsulated with both a filtering media **1100** and an overlying clear media **600** (FIG. **6**), i.e. attenuated. In a particular embodiment, the filtering media **1100** is a 40:1 mixture of a clear encapsulant (EPO-TEK OG147-7) and an opaque encapsulate (EPO-TEK OG147) both available from Epoxy Technology, Inc., Billerica, Mass. Three LEDs nominally emitting at 610-630 nm are only encapsulated with the clear media **600** (FIG. **6**), i.e. unattenuated. In alternative embodiments, individual LEDs may be singly or multiply encapsulated according to tissue absorption and/or output intensity. In other alternative embodiments, filtering media may be separately attachable

optical filters or a combination of encapsulants and separately attachable optical filters. In a particular embodiment, the emitter assembly **500** has one or more notches along each side proximate the component end **1305** (FIG. **13**) for retaining one or more clip-on optical filters.

Substrate

FIG. **12** illustrates light emitters **710** configured to transmit optical radiation **1201** having multiple wavelengths in response to corresponding drive currents **1210**. A thermal mass **1220** is disposed proximate the emitters **710** so as to stabilize a bulk temperature **1202** for the emitters. A temperature sensor **1230** is thermally coupled to the thermal mass **1220**, wherein the temperature sensor **1230** provides a temperature sensor output **1232** responsive to the bulk temperature **1202** so that the wavelengths are determinable as a function of the drive currents **1210** and the bulk temperature **1202**.

In one embodiment, an operating wavelength λ_a of each light emitter **710** is determined according to EQ. 3

$$\lambda_a = f(T_b, I_{drive}, \Sigma I_{drive}) \quad (3)$$

where T_b is the bulk temperature, I_{drive} is the drive current for a particular light emitter, as determined by the sensor controller **4500** (FIG. **45**), described below, and ΣI_{drive} is the total drive current for all light emitters. In another embodiment, temperature sensors are configured to measure the temperature of each light emitter **710** and an operating wavelength λ_a of each light emitter **710** is determined according to EQ. 4

$$\lambda_a = f(T_a, I_{drive}, \Sigma I_{drive}) \quad (4)$$

where T_a is the temperature of a particular light emitter, I_{drive} is the drive current for that light emitter and ΣI_{drive} is the total drive current for all light emitters.

In yet another embodiment, an operating wavelength for each light emitter is determined by measuring the junction voltage for each light emitter **710**. In a further embodiment, the temperature of each light emitter **710** is controlled, such as by one or more Peltier cells coupled to each light emitter **710**, and an operating wavelength for each light emitter **710** is determined as a function of the resulting controlled temperature or temperatures. In other embodiments, the operating wavelength for each light emitter **710** is determined directly, for example by attaching a charge coupled device (CCD) to each light emitter or by attaching a fiberoptic to each light emitter and coupling the fiberoptics to a wavelength measuring device, to name a few.

FIGS. **13-18** illustrate one embodiment of a substrate **1200** configured to provide thermal conductivity between an emitter array **700** (FIG. **8**) and a thermistor **1540** (FIG. **16**). In this manner, the resistance of the thermistor **1540** (FIG. **16**) can be measured in order to determine the bulk temperature of LEDs **801** (FIG. **8**) mounted on the substrate **1200**. The substrate **1200** is also configured with a relatively significant thermal mass, which stabilizes and normalizes the bulk temperature so that the thermistor measurement of bulk temperature is meaningful.

FIGS. **13-14** illustrate a substrate **1200** having a component side **1301**, a solder side **1302**, a component end **1305** and a connector end **1306**. Alignment notches **1310** are disposed between the ends **1305**, **1306**. The substrate **1200** further has a component layer **1401**, inner layers **1402-1405** and a solder layer **1406**. The inner layers **1402-1405**, e.g. inner layer **1402** (FIG. **18**), have substantial metallized areas **1411** that provide a thermal mass **1220** (FIG. **12**) to stabilize a bulk temperature for the emitter array **700** (FIG. **12**). The

metallized areas 1411 also function to interconnect component pads 1510 and wire bond pads 1520 (FIG. 15) to the connector 1530.

FIGS. 15-16 illustrate a substrate 1200 having component pads 1510 and wire bond pads 1520 at a component end 1305. The component pads 1510 mount and electrically connect a first side (anode or cathode) of the LEDs 801 (FIG. 8) to the substrate 1200. Wire bond pads 1520 electrically connect a second side (cathode or anode) of the LEDs 801 (FIG. 8) to the substrate 1200. The connector end 1306 has a connector 1530 with connector pads 1532, 1534 that mount and electrically connect the emitter assembly 500 (FIG. 23), including the substrate 1200, to the flex circuit 2200 (FIG. 22). Substrate layers 1401-1406 (FIG. 14) have traces that electrically connect the component pads 1510 and wire bond pads 1520 to the connector 1532-1534. A thermistor 1540 is mounted to thermistor pads 1550 at the component end 1305, which are also electrically connected with traces to the connector 1530. Plated thru holes electrically connect the connector pads 1532, 1534 on the component and solder sides 1301, 1302, respectively.

FIG. 17 illustrates the electrical layout of a substrate 1200. A portion of the LEDs 801, including D1-D4 and D13-D16 have cathodes physically and electrically connected to component pads 1510 (FIG. 15) and corresponding anodes wire bonded to wire bond pads 1520. Another portion of the LEDs 801, including D5-D8 and D9-D12, have anodes physically and electrically connected to component pads 1510 (FIG. 15) and corresponding cathodes wire bonded to wire bond pads 1520. The connector 1530 has row pinouts J21-J24, column pinouts J31-J34 and thermistor pinouts J40-J41 for the LEDs 801 and thermistor 1540. Interconnect Assembly

FIG. 19 illustrates an interconnect assembly 1900 that mounts the emitter assembly 500 and detector assembly 2400, connects to the sensor cable 4400 and provides electrical communications between the cable and each of the emitter assembly 500 and detector assembly 2400. In one embodiment, the interconnect assembly 1900 is incorporated with the attachment assembly 2700, which holds the emitter and detector assemblies to a tissue site. An interconnect assembly embodiment utilizing a flexible (flex) circuit is described with respect to FIGS. 20-24, below.

FIG. 20 illustrates an interconnect assembly 1900 embodiment having a circuit substrate 2200, an emitter mount 2210, a detector mount 2220 and a cable connector 2230. The emitter mount 2210, detector mount 2220 and cable connector 2230 are disposed on the circuit substrate 2200. The emitter mount 2210 is adapted to mount an emitter assembly 500 having multiple emitters. The detector mount 2220 is adapted to mount a detector assembly 2400 having a detector. The cable connector 2230 is adapted to attach a sensor cable 4400. A first plurality of conductors 2040 disposed on the circuit substrate 2200 electrically interconnects the emitter mount 2210 and the cable connector 2230. A second plurality of conductors 2050 disposed on the circuit substrate 2200 electrically interconnects the detector mount 2220 and the cable connector 2230. A decoupling 2060 disposed proximate the cable connector 2230 substantially mechanically isolates the cable connector 2230 from both the emitter mount 2210 and the detector mount 2220 so that sensor cable stiffness is not translated to the emitter assembly 500 or the detector assembly 2400. A shield 2070 is adapted to fold over and shield one or more wires or pairs of wires of the sensor cable 4400.

FIG. 21 illustrates a flex circuit assembly 1900 having a flex circuit 2200, an emitter assembly 500 and a detector

assembly 2400, which is configured to terminate the sensor end of a sensor cable 4400. The flex circuit assembly 1900 advantageously provides a structure that electrically connects yet mechanically isolates the sensor cable 4400, the emitter assembly 500 and the detector assembly 2400. As a result, the mechanical stiffness of the sensor cable 4400 is not translated to the sensor pads 3000, 3100 (FIGS. 30-31), allowing a comfortable finger attachment for the sensor 200 (FIG. 1). In particular, the emitter assembly 500 and detector assembly 2400 are mounted to opposite ends 2201, 2202 (FIG. 22) of an elongated flex circuit 2200. The sensor cable 4400 is mounted to a cable connector 2230 extending from a middle portion of the flex circuit 2200. Detector wires 4470 are shielded at the flex circuit junction by a fold-over conductive ink flap 2240, which is connected to a cable inner shield 4450. The flex circuit 2200 is described in further detail with respect to FIG. 22. The emitter portion of the flex circuit assembly 1900 is described in further detail with respect to FIG. 23. The detector assembly 2400 is described with respect to FIG. 24. The sensor cable 4400 is described with respect to FIGS. 44A-B, below.

FIG. 22 illustrates a sensor flex circuit 2200 having an emitter end 2201, a detector end 2202, an elongated interconnect 2204, 2206 between the ends 2201, 2202 and a cable connector 2230 extending from the interconnect 2204, 2206. The emitter end 2201 forms a "head" having emitter solder pads 2210 for attaching the emitter assembly 500 (FIG. 6) and mounting ears 2214 for attaching to the emitter pad 3000 (FIG. 30B), as described below. The detector end 2202 has detector solder pads for attaching the detector 2410 (FIG. 24). The interconnect 2204 between the emitter end 2201 and the cable connector 2230 forms a "neck," and the interconnect 2206 between the detector end 2202 and the cable connector 2230 forms a "tail." The cable connector 2230 forms "wings" that extend from the interconnect 2204, 2206 between the neck 2204 and tail 2206. A conductive ink flap 2240 connects to the cable inner shield 4450 (FIGS. 44A-B) and folds over to shield the detector wires 4470 (FIGS. 44A-B) soldered to the detector wire pads 2236. The outer wire pads 2238 connect to the remaining cable wires 4430 (FIGS. 44A-B). The flex circuit 2200 has top coverlay, top ink, inner coverlay, trace, trace base, bottom ink and bottom coverlay layers.

The flex circuit 2200 advantageously provides a connection between a multiple wire sensor cable 4400 (FIGS. 44A-B), a multiple wavelength emitter assembly 500 (FIG. 6) and a detector assembly 2400 (FIG. 24) without rendering the emitter and detector assemblies unwieldy and stiff. In particular, the wings 2230 provide a relatively large solder pad area 2232 that is narrowed at the neck 2204 and tail 2206 to mechanically isolate the cable 4400 (FIGS. 44A-B) from the remainder of the flex circuit 2200. Further, the neck 2206 is folded (see FIG. 4) for installation in the emitter pad 3000 (FIGS. 30A-H) and acts as a flexible spring to further mechanically isolate the cable 4400 (FIGS. 44A-B) from the emitter assembly 500 (FIG. 4). The tail 2206 provides an integrated connectivity path between the detector assembly 2400 (FIG. 24) mounted in the detector pad 3100 (FIGS. 31A-H) and the cable connector 2230 mounted in the opposite emitter pad 3000 (FIGS. 30A-H).

FIG. 23 illustrates the emitter portion of the flex circuit assembly 1900 (FIG. 21) having the emitter assembly 500. The emitter assembly connector 1530 is attached to the emitter end 2210 of the flex circuit 2200 (FIG. 22). In particular, reflow solder 2330 connects thru hole pads 1532, 1534 of the emitter assembly 500 to corresponding emitter pads 2310 of the flex circuit 2200 (FIG. 22).

FIG. 24 illustrates a detector assembly 2400 including a detector 2410, solder pads 2420, copper mesh tape 2430, an EMI shield 2440 and foil 2450. The detector 2410 is soldered 2460 chip side down to detector solder pads 2420 of the flex circuit 2200. The detector solder joint and detector ground pads 2420 are wrapped with the Kapton tape 2470. EMI shield tabs 2442 are folded onto the detector pads 2420 and soldered. The EMI shield walls are folded around the detector 2410 and the remaining tabs 2442 are soldered to the back of the EMI shield 2440. The copper mesh tape 2430 is cut to size and the shielded detector and flex circuit solder joint are wrapped with the copper mesh tape 2430. The foil 2450 is cut to size with a predetermined aperture 2452. The foil 2450 is wrapped around shielded detector with the foil side in and the aperture 2452 is aligned with the EMI shield grid 2444.

Detector Assembly

FIG. 25 illustrates an alternative detector assembly 2400 embodiment having adjacent detectors. Optical radiation having multiple wavelengths generated by emitters 700 is transmitted into a tissue site 1. Optical radiation at a first set of wavelengths is detected by a first detector 2510, such as, for example, a Si detector. Optical radiation at a second set of wavelengths is detected by a second detector 2520, such as, for example, a GaAs detector.

FIG. 26 illustrates another alternative detector assembly 2400 embodiment having stacked detectors coaxial along a light path. Optical radiation having multiple wavelengths generated by emitters 700 is transmitted into a tissue site 1. Optical radiation at a first set of wavelengths is detected by a first detector 2610. Optical radiation at a second set of wavelengths passes through the first detector 2610 and is detected by a second detector 2620. In a particular embodiment, a silicon (Si) detector and a gallium arsenide (GaAs) detector are used. The Si detector is placed on top of the GaAs detector so that light must pass through the Si detector before reaching the GaAs detector. The Si detector can be placed directly on top of the GaAs detector or the Si and GaAs detector can be separated by some other medium, such as a transparent medium or air. In another particular embodiment, a germanium detector is used instead of the GaAs detector. Advantageously, the stacked detector arrangement minimizes error caused by pathlength differences as compared with the adjacent detector embodiment.

Finger Clip

FIG. 27 illustrates a finger clip embodiment 2700 of a physiological sensor attachment assembly. The finger clip 2700 is configured to removably attach an emitter assembly 500 (FIG. 6) and detector assembly 2400 (FIG. 24), interconnected by a flex circuit assembly 1900, to a fingertip. The finger clip 2700 has an emitter shell 3800, an emitter pad 3000, a detector pad 2800 and a detector shell 3900. The emitter shell 3800 and the detector shell 3900 are rotatably connected and urged together by the spring assembly 3500. The emitter pad 3000 is fixedly retained by the emitter shell. The emitter assembly 500 (FIG. 6) is mounted proximate the emitter pad 3000 and adapted to transmit optical radiation having a plurality of wavelengths into fingertip tissue. The detector pad 2800 is fixedly retained by the detector shell 3900. The detector assembly 3500 is mounted proximate the detector pad 2800 and adapted to receive the optical radiation after attenuation by fingertip tissue.

FIG. 28 illustrates a detector pad 2800 advantageously configured to position and comfortably maintain a fingertip relative to a detector assembly for accurate sensor measurements. In particular, the detector pad has fingertip positioning features including a guide 2810, a contour 2820 and a

stop 2830. The guide 2810 is raised from the pad surface 2803 and narrows as the guide 2810 extends from a first end 2801 to a second end 2802 so as to increasingly conform to a fingertip as a fingertip is inserted along the pad surface 2803 from the first end 2801. The contour 2820 has an indentation defined along the pad surface 2803 generally shaped to conform to a fingertip positioned over a detector aperture 2840 located within the contour 2820. The stop 2830 is raised from the pad surface 2803 so as to block the end of a finger from inserting beyond the second end 2802. FIGS. 29A-B illustrate detector pad embodiments 3100, 3400 each having a guide 2810, a contour 2820 and a stop 2830, described in further detail with respect to FIGS. 31 and 34, respectively.

FIGS. 30A-H illustrate an emitter pad 3000 having emitter pad flaps 3010, an emitter window 3020, mounting pins 3030, an emitter assembly cavity 3040, isolation notches 3050, a flex circuit notch 3070 and a cable notch 3080. The emitter pad flaps 3010 overlap with detector pad flaps 3110 (FIGS. 31A-H) to block ambient light. The emitter window 3020 provides an optical path from the emitter array 700 (FIG. 8) to a tissue site. The mounting pins 3030 accommodate apertures in the flex circuit mounting ears 2214 (FIG. 22), and the cavity 3040 accommodates the emitter assembly 500 (FIG. 21). Isolation notches 3050 mechanically decouple the shell attachment 3060 from the remainder of the emitter pad 3000. The flex circuit notch 3070 accommodates the flex circuit tail 2206 (FIG. 22) routed to the detector pad 3100 (FIGS. 31A-H). The cable notch 3080 accommodates the sensor cable 4400 (FIGS. 44A-B). FIGS. 33A-H illustrate an alternative slim finger emitter pad 3300 embodiment.

FIGS. 31A-H illustrate a detector pad 3100 having detector pad flaps 3110, a shoe box cavity 3120 and isolation notches 3150. The detector pad flaps 3110 overlap with emitter pad flaps 3010 (FIGS. 30A-H), interleaving to block ambient light. The shoe box cavity 3120 accommodates a shoe box 3200 (FIG. 32A-H) described below. Isolation notches 3150 mechanically decouple the attachment points 3160 from the remainder of the detector pad 3100. FIGS. 34A-H illustrate an alternative slim finger detector pad 3400 embodiment.

FIGS. 32A-H illustrate a shoe box 3200 that accommodates the detector assembly 2400 (FIG. 24). A detector window 3210 provides an optical path from a tissue site to the detector 2410 (FIG. 24). A flex circuit notch 3220 accommodates the flex circuit tail 2206 (FIG. 22) routed from the emitter pad 3000 (FIGS. 30A-H). In one embodiment, the shoe box 3200 is colored black or other substantially light absorbing color and the emitter pad 3000 and detector pad 3100 are each colored white or other substantially light reflecting color.

FIGS. 35-37 illustrate a spring assembly 3500 having a spring 3600 configured to urge together an emitter shell 3800 (FIG. 46) and a detector shell 3900. The detector shell is rotatably connected to the emitter shell. The spring is disposed between the shells 3800, 3900 and adapted to create a pivot point along a finger gripped between the shells that is substantially behind the fingertip. This advantageously allows the shell hinge 3810, 3910 (FIGS. 38-39) to expand so as to distribute finger clip force along the inserted finger, comfortably keeping the fingertip in position over the detector without excessive force.

As shown in FIGS. 36A-C, the spring 3600 has coils 3610, an emitter shell leg 3620 and a detector shell leg 3630. The emitter shell leg 3620 presses against the emitter shell 3800 (FIGS. 38A-D) proximate a grip 3820 (FIGS. 38A-D).

The detector shell legs **3630** extend along the detector shell **3900** (FIGS. **39A-D**) to a spring plate **3700** (FIGS. **37A-D**) attachment point. The coil **3610** is secured by hinge pins **410** (FIG. **46**) and is configured to wind as the finger clip is opened, reducing its diameter and stress accordingly.

As shown in FIGS. **37A-D** the spring plate **3700** has attachment apertures **3710**, spring leg slots **3720**, and a shelf **3730**. The attachment apertures **3710** accept corresponding shell posts **3930** (FIGS. **39A-D**) so as to secure the spring plate **3700** to the detector shell **3900** (FIG. **39A-D**). Spring legs **3630** (FIG. **36A-C**) are slidably anchored to the detector shell **3900** (FIG. **39A-D**) by the shelf **3730**, advantageously allowing the combination of spring **3600**, shells **3800**, **3900** and hinges **3810**, **3910** to adjust to various finger sizes and shapes.

FIGS. **38-39** illustrate the emitter and detector shells **3800**, **3900**, respectively, having hinges **3810**, **3910** and grips **3820**, **3920**. Hinge apertures **3812**, **3912** accept hinge pins **410** (FIG. **46**) so as to create a finger clip. The detector shell hinge aperture **3912** is elongated, allowing the hinge to expand to accommodate a finger.

Monitor and Sensor

FIG. **40** illustrates a monitor **100** and a corresponding sensor assembly **200**, as described generally with respect to FIGS. **1-3**, above. The sensor assembly **200** has a sensor **400** and a sensor cable **4400**. The sensor **400** houses an emitter assembly **500** having emitters responsive to drivers within a sensor controller **4500** so as to transmit optical radiation into a tissue site. The sensor **400** also houses a detector assembly **2400** that provides a sensor signal **2500** responsive to the optical radiation after tissue attenuation. The sensor signal **2500** is filtered, amplified, sampled and digitized by the front-end **4030** and input to a DSP (digital signal processor) **4040**, which also commands the sensor controller **4500**. The sensor cable **4400** electrically communicates drive signals from the sensor controller **4500** to the emitter assembly **500** and a sensor signal **2500** from the detector assembly **2400** to the front-end **4030**. The sensor cable **4400** has a monitor connector **210** that plugs into a monitor sensor port **110**.

In one embodiment, the monitor **100** also has a reader **4020** capable of obtaining information from an information element (IE) in the sensor assembly **200** and transferring that information to the DSP **4040**, to another processor or component within the monitor **100**, or to an external component or device that is at least temporarily in communication with the monitor **100**. In an alternative embodiment, the reader function is incorporated within the DSP **4040**, utilizing one or more of DSP I/O, ADC, DAC features and corresponding processing routines, as examples.

In one embodiment, the monitor connector **210** houses the information element **4000**, which may be a memory device or other active or passive electrical component. In a particular embodiment, the information element **4000** is an EPROM, or other programmable memory, or an EEPROM, or other reprogrammable memory, or both. In an alternative embodiment, the information element **4000** is housed within the sensor **400**, or an information element **4000** is housed within both the monitor connector **4000** and the sensor **400**. In yet another embodiment, the emitter assembly **500** has an information element **4000**, which is read in response to one or more drive signals from the sensor controller **4500**, as described with respect to FIGS. **41-43**, below. In a further embodiment, a memory information element is incorporated into the emitter array **700** (FIG. **8**) and has characterization information relating to the LEDs **801** (FIG. **8**). In one advantageous embodiment, trend data relating to slowly

varying parameters, such as perfusion index, HbCO or METHb, to name a few, are stored in an IE memory device, such as EEPROM.

Back-to-Back LEDs

FIGS. **41-43** illustrate alternative sensor embodiments. A sensor controller **4500** configured to activate an emitter array **700** (FIG. **7**) arranged in an electrical grid, is described with respect to FIG. **7**, above. Advantageously, a sensor controller **4500** so configured is also capable of driving a conventional two-wavelength (red and IR) sensor **4100** having back-to-back LEDs **4110**, **4120** or an information element **4300** or both.

FIG. **41A** illustrates a sensor **4100** having an electrical grid **4130** configured to activate light emitting sources by addressing at least one row conductor and at least one column conductor. A first LED **4110** and a second LED **4120** are configured in a back-to-back arrangement so that a first contact **4152** is connected to a first LED **4110** cathode and a second LED **4120** anode and a second contact **4154** is connected to a first LED **4110** anode and a second LED **4120** cathode. The first contact **4152** is in communications with a first row conductor **4132** and a first column conductor **4134**. The second contact is in communications with a second row conductor **4136** and a second column conductor **4138**. The first LED **4110** is activated by addressing the first row conductor **4132** and the second column conductor **4138**. The second LED **4120** is activated by addressing the second row conductor **4136** and the first column conductor **4134**.

FIG. **41B** illustrates a sensor cable **4400** embodiment capable of communicating signals between a monitor **100** and a sensor **4100**. The cable **4400** has a first row input **4132**, a first column input **4134**, a second row input **4136** and a second column input **4138**. A first output **4152** combines the first row input **4132** and the first column input **4134**. A second output **4154** combines a second row input **4136** and second column input **4138**.

FIG. **41C** illustrates a monitor **100** capable of communicating drive signals to a sensor **4100**. The monitor **4400** has a first row signal **4132**, a first column signal **4134**, a second row signal **4136** and a second column signal **4138**. A first output signal **4152** combines the first row signal **4132** and the first column signal **4134**. A second output signal **4154** combines a second row signal **4136** and second column signal **4138**.

Information Elements

FIGS. **42-43** illustrate information element **4200-4300** embodiments in communications with emitter array drivers configured to activate light emitters connected in an electrical grid. The information elements are configured to provide information as DC values, AC values or a combination of DC and AC values in response corresponding DC, AC or combination DC and AC electrical grid drive signals. FIG. **42** illustrates information element embodiment **4200** advantageously driven directly by an electrical grid having rows **710** and columns **720**. In particular, the information element **4200** has a series connected resistor R_2 **4210** and diode **4220** connected between a row line **710** and a column line **720** of an electrical grid. In this manner, the resistor R_2 value can be read in a similar manner that LEDs **810** (FIG. **8**) are activated. The diode **4220** is oriented, e.g. anode to row and cathode to column as the LEDs so as to prevent parasitic currents from unwanted activation of LEDs **810** (FIG. **8**).

FIGS. **43A-C** illustrate other embodiments where the value of R_1 is read with a DC grid drive current and a corresponding grid output voltage level. In other particular embodiments, the combined values of R_1 , R_2 and C or,

alternatively, R_1 , R_2 and L are read with a varying (AC) grid drive currents and a corresponding grid output voltage waveform. As one example, a step in grid drive current is used to determine component values from the time constant of a corresponding rise in grid voltage. As another example, a sinusoidal grid drive current is used to determine component values from the magnitude or phase or both of a corresponding sinusoidal grid voltage. The component values determined by DC or AC electrical grid drive currents can represent sensor types, authorized suppliers or manufacturers, emitter wavelengths among others. Further, a diode D (FIG. 43C) can be used to provide one information element reading R_1 at one drive level or polarity and another information element reading, combining R_1 and R_2 , at a second drive level or polarity, i.e. when the diode is forward biased.

Passive information element 4300 embodiments may include any of various combinations of resistors, capacitors or inductors connected in series and parallel, for example. Other information element 4300 embodiments connected to an electrical grid and read utilizing emitter array drivers incorporate other passive components, active components or memory components, alone or in combination, including transistor networks, PROMs, ROMs, EPROMs, EEPROMs, gate arrays and PLAs to name a few.

Sensor Cable

FIGS. 44A-B illustrate a sensor cable 4400 having an outer jacket 4410, an outer shield 4420, multiple outer wires 4430, an inner jacket 4440, an inner shield 4450, a conductive polymer 4460 and an inner twisted wire pair 4470. The outer wires 4430 are advantageously configured to compactly carry multiple drive signals to the emitter array 700 (FIG. 7). In one embodiment, there are twelve outer wires 4430 corresponding to four anode drive signals 4501 (FIG. 45), four cathode drive signals 4502 (FIG. 45), two thermistor pinouts 1450 (FIG. 15) and two spares. The inner twisted wire pair 4470 corresponds to the sensor signal 2500 (FIG. 25) and is extruded within the conductive polymer 4460 so as to reduce triboelectric noise. The shields 4420, 4450 and the twisted pair 4470 boost EMI and crosstalk immunity for the sensor signal 2500 (FIG. 25).

Controller

FIG. 45 illustrates a sensor controller 4500 located in the monitor 100 (FIG. 1) and configured to provide anode drive signals 4501 and cathode drive signals 4502 to the emitter array 700 (FIG. 7). The DSP (digital signal processor) 4040, which performs signal processing functions for the monitor, also provides commands 4042 to the sensor controller 4500. These commands determine drive signal 4501, 4502 levels and timing. The sensor controller 4500 has a command register 4510, an anode selector 4520, anode drivers 4530, current DACs (digital-to-analog converters) 4540, a current multiplexer 4550, cathode drivers 4560, a current meter 4570 and a current limiter 4580. The command register 4510 provides control signals responsive to the DSP commands 4042. In one embodiment, the command register 4510 is a shift register that loads serial command data 4042 from the DSP 4040 and synchronously sets output bits that select or enable various functions within the sensor controller 4500, as described below.

As shown in FIG. 45, the anode selector 4520 is responsive to anode select 4516 inputs from the command register 4510 that determine which emitter array row 810 (FIG. 8) is active. Accordingly, the anode selector 4520 sets one of the anode on 4522 outputs to the anode drivers 4530, which pulls up to V_{cc} one of the anode outputs 4501 to the emitter array 700 (FIG. 8).

Also shown in FIG. 45, the current DACs 4540 are responsive to command register data 4519 that determines the currents through each emitter array column 820 (FIG. 8). In one embodiment, there are four, 12-bit DACs associated with each emitter array column 820 (FIG. 8), sixteen DACs in total. That is, there are four DAC outputs 4542 associated with each emitter array column 820 (FIG. 8) corresponding to the currents associated with each row 810 (FIG. 8) along that column 820 (FIG. 8). In a particular embodiment, all sixteen DACs 4540 are organized as a single shift register, and the command register 4510 serially clocks DAC data 4519 into the DACs 4540. A current multiplexer 4550 is responsive to cathode on 4518 inputs from the command register 4510 and anode on 4522 inputs from the anode selector 4520 so as to convert the appropriate DAC outputs 4542 to current set 4552 inputs to the cathode drivers 4560. The cathode drivers 4560 are responsive to the current set 4552 inputs to pull down to ground one to four of the cathode outputs 4502 to the emitter array 700 (FIG. 8).

The current meter 4570 outputs a current measure 4572 that indicates the total LED current driving the emitter array 700 (FIG. 8). The current limiter 4580 is responsive to the current measure 4572 and limits specified by the command register 4510 so as to prevent excessive power dissipation by the emitter array 700 (FIG. 8). The current limiter 4580 provides an enable 4582 output to the anode selector 4520. A Hi Limit 4512 input specifies the higher of two preset current limits. The current limiter 4580 latches the enable 4582 output in an off condition when the current limit is exceeded, disabling the anode selector 4520. A trip reset 4514 input resets the enable 4582 output to re-enable the anode selector 4520.

Sensor Assembly

As shown in FIG. 46, the sensor 400 has an emitter shell 3800, an emitter pad 3000, a flex circuit assembly 2200, a detector pad 3100 and a detector shell 3900. A sensor cable 4400 attaches to the flex circuit assembly 2200, which includes a flex circuit 2100, an emitter assembly 500 and a detector assembly 2400. The portion of the flex circuit assembly 2200 having the sensor cable 4400 attachment and emitter assembly 500 is housed by the emitter shell 3800 and emitter pad 3000. The portion of the flex circuit assembly 2200 having the detector assembly 2400 is housed by the detector shell 3900 and detector pad 3100. In particular, the detector assembly 2400 inserts into a shoe 3200, and the shoe 3200 inserts into the detector pad 3100. The emitter shell 3800 and detector shell 3900 are fastened by and rotate about hinge pins 410, which insert through coils of a spring 3600. The spring 3600 is held to the detector shell 3900 with a spring plate 3700. A finger stop 450 attaches to the detector shell. In one embodiment, a silicon adhesive 420 is used to attach the pads 3000, 3100 to the shells 3800, 3900, a silicon potting compound 430 is used to secure the emitter and detector assemblies 500, 2400 within the pads 3000, 3100, and a cyanoacrylic adhesive 440 secures the sensor cable 4400 to the emitter shell 3800.

A multiple wavelength sensor has been disclosed in detail in connection with various embodiments. These embodiments are disclosed by way of examples only and are not to limit the scope of the claims that follow. One of ordinary skill in art will appreciate many variations and modifications.

What is claimed is:

1. A physiological sensor configured to measure an indication of a physiological characteristic of a living patient, the physiological sensor comprising:

a plurality of light emitting sources arranged to impinge light on body tissue of the living patient including at least six light emitting sources, wherein the plurality of light emitting sources emit light of at least three different wavelengths, and wherein at least one of the light emitting sources is activated by addressing a first row of a plurality of rows and a first column of a plurality of columns of an electrical grid;

at least one information element configured to convey information about the physiological sensor, wherein the at least one information element is activated by addressing a second row of the plurality of rows and a second column of the plurality of columns of the electrical grid;

a detector responsive to transmitted light after attenuation by body tissue of the living patient, the body tissue including pulsating blood, wherein the detector is configured to generate a signal indicative of a physiological characteristic of the living patient; and

a sensor housing configured to position the plurality of light emitting sources and the detector with respect to the body tissue of the living patient.

2. The physiological sensor of claim 1, wherein the information element comprises at least one circuit comprising a resistor and a diode.

3. The physiological sensor of claim 2, wherein the diode comprises an anode and a cathode, the anode being proximal to the second row of the plurality of rows with respect to the cathode and the cathode being proximal to the second column of the plurality of columns with respect to the anode.

4. The physiological sensor of claim 3, wherein the diode is oriented to prevent parasitic currents from activating the plurality of light emitting sources.

5. The physiological sensor of claim 1, wherein the information element comprises a circuit comprising a first resistor, a second resistor, and a capacitor, and wherein the second resistor is in series with the capacitor and the first resistor is in parallel with the second resistor and the capacitor.

6. The physiological sensor of claim 1, wherein the information element comprises a circuit comprising a first resistor, a second resistor, and an inductor, and wherein the second resistor is in parallel with the inductor and the first resistor is in series with the second resistor and the inductor.

7. The physiological sensor of claim 1, wherein the information element comprises a circuit comprising a first resistor, a second resistor, and a diode, and wherein the second resistor is in series with the diode and the first resistor is in parallel with the second resistor and the diode.

8. The physiological sensor of claim 7 wherein the information element is configured to convey a first set of information at a first polarity and convey a second set of information at a second polarity, wherein the diode is forward biased at the second polarity.

9. The physiological sensor of claim 8, wherein the first set of information is indicative of a value of the first resistor and the second set of information is indicative of a combined value of the first and second resistors.

10. The physiological sensor of claim 1, wherein the information element comprises at least one of transistor networks, Programmable Read-Only Memory (PROM), Read-Only Memory (ROM), Erasable Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM), gate arrays, and or Programmable Logic Arrays (PLA).

11. The physiological sensor of claim 1, wherein the information element is configured to convey information comprising at least one of sensor type, authorized suppliers, authorized manufacturers, or emitter wavelengths.

12. The physiological sensor of claim 1, wherein at least a subset of the plurality of light emitting sources are further arranged in two or more clusters, each cluster comprising at least two light emitting sources that emit light within a wavelength range that is different from and does not overlap with the wavelength range of the at least two light emitting sources of other clusters.

13. The physiological sensor of claim 12, wherein for each cluster, light emitting sources that emit light at proximate wavelengths are adjacent to each other.

14. A method for measuring an indication of a physiological characteristic of a living patient, the method comprising: positioning a sensor with respect to body tissue of the living patient, the sensor comprising:

- a detector,
- a plurality of light emitting sources configured to emit light of at least three different wavelengths, the plurality of light emitting sources comprising at least six light emitting sources, and
- at least one information element configured to convey information about the physiological sensor,

wherein the plurality of light emitting sources and the at least one information element are arranged as elements in an electrical grid comprising rows and columns such that any element may be individually activated;

activating the information element, said activating comprising addressing at least one of the rows and at least one of the columns of the electrical grid;

determining at least one of sensor type, authorized supplier, authorized manufacturer, or emitter wavelength based at least in part on the activation of the information element; and

generating a signal indicative of a physiological characteristic of the living patient responsive to detected light.

15. The method of claim 14, wherein the information element comprises at least one circuit comprising a resistor and a diode.

16. The method of claim 14, wherein the information element comprises a circuit comprising a first resistor, a second resistor, and a capacitor, and wherein the second resistor is in series with the capacitor and the first resistor is in parallel with the second resistor and the capacitor.

17. The method of claim 14, wherein the information element comprises a circuit comprising a first resistor, a second resistor, and an inductor, and wherein the second resistor is in parallel with the inductor and the first resistor is in series with the second resistor and the inductor.

18. The method of claim 14, wherein the information element comprises a circuit comprising a first resistor, a second resistor, and a diode, and wherein the second resistor is in series with the diode and the first resistor is in parallel with the second resistor and the diode.

19. The method of claim 14, wherein the information element comprises at least one of transistor networks, Programmable Read-Only Memory (PROM), Read-Only Memory (ROM), Erasable Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM), gate arrays, and or Programmable Logic Arrays (PLA).